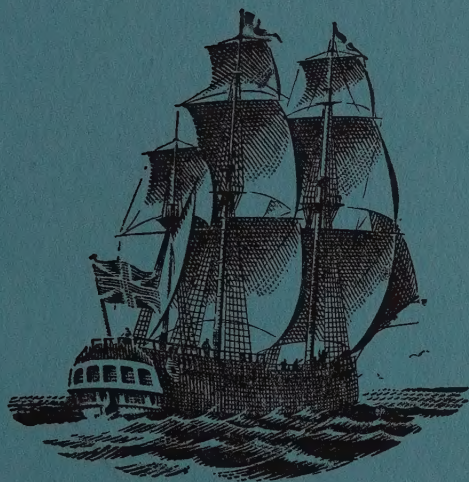


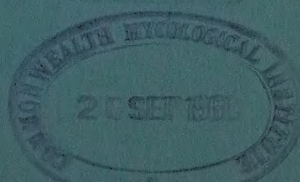
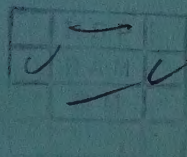
ENDEAVOUR



Volume XIX

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ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, occasional articles from overseas contributors are included and impartial reference is made to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in 1768 to chart the South Pacific Ocean and observe the transit of Venus

ENDEAVOUR

A quarterly review, published in five languages,
designed to record the progress of the sciences
in the service of mankind

VOLUME XIX

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The Chelsea Physic Garden

The Chelsea Physic Garden plays an unusual, possibly unique, part among the numerous and varied institutions in Britain devoted to the scientific study of plants. Most botanists know it as the second oldest physic garden in the British Isles, about fifty years younger than the one at Oxford and nearly a hundred years older than the Botanic Gardens at Kew. The land was the gift of Sir Hans Sloane, President of the Royal Society from 1727 to 1741: this year marks the tercentenary of both Sloane's birth and the foundation of the Royal Society. After nearly three hundred years the garden's activities are greater and more varied than ever before.

In 1673 the Society of Apothecaries signed a lease for a piece of land on the banks of the Thames, just outside what was then the village of Chelsea, to allow convenient water carriage to Apothecaries Hall at Blackfriars. A dock for the barges survives as a garden yard, but it is now high and dry, having been separated from the river, like the rest of the garden, by the building of Chelsea Embankment. The original purpose of the Chelsea Physic Garden, which it shared with other early physic and botanic gardens, was the cultivation, for strictly educational purposes, of drug plants used in the pharmacopoeias of their time, and this function has survived without a break to the present day. The garden has gradually seen its rural surroundings become wholly urban and its survival is a matter for surprise.

The Society walled in its plot the year after leasing it, and the freehold was conveyed to it in 1722 by Sir Hans Sloane, who had acquired it with the Manor of Chelsea ten years previously. The purpose of the conveyance was that it might be continued as a physic garden and 'that the apprentices of the Society and others might better distinguish good and useful plants from those that bear resemblance to them and yet are hurtful'. One of the conditions of the transfer was that the Apothecaries should yearly render to the Royal Society fifty specimens of distinct plants, well dried and preserved, which had grown in the garden that year. Sir Hans, as President of the Royal Society, gave a dinner to his colleagues on the occasion when the officials of the Worshipful Society of Apothecaries paid their annual tribute, and the specimens were inspected and discussed by those present.

To commemorate the munificence of Sloane,

a portrait statue in marble by Michael Rysbrach was set up in the garden in 1737. It stands there still, reasonably well preserved in spite of the London atmosphere. This year being the three-hundredth anniversary of Sloane's birth, the statue has been given special attention and now stands startlingly white among the gentle greens and greys of the surrounding garden and its boundary walls.

The garden has been under the charge of a long series of Gardeners or Curators, some of whom are well known in the history of horticulture. Phillip Miller (appointed 1722), 'the most famous gardener of his day', was Curator for forty-eight years. By 1768 his 'Gardener's Dictionary' had reached its eighth edition. One of the aims of Linnaeus in his trip to England in 1736 was to visit Chelsea, and he records that Miller permitted him to collect many plants in the garden. Miller was succeeded by James Forsyth, who became noted for his methods of pruning and training fruit-bearing and forest trees; for him the shrub genus *Forsythia* is named, without which no suburban garden is now complete. Robert Fortune, the famous collector, was appointed in 1846, but was released at the request of the East India Company two years later to undertake the importation of tea into India: the genus *Fortunella* (the cumquats) derives its name from him.

For over a century, starting in 1724, there was also a Director of the Garden and Demonstrator of Plants. One was William Curtis [ENDEAVOUR, Vol. v, 13, 1946], author of the *Flora Londinensis*, 'one of the most beautiful and accurate works on British plants', and originator of the *Botanical Magazine*; the latter first appeared in 1787 and is still published and associated with his name. John Lindley—appointed in 1835—with the co-operation of Fortune during his short period as a Curator, reorganized the garden on a natural system and with Thomas Moore, the next Curator, compiled the celebrated 'Treasury of Botany' that for many years remained a valuable work of reference on economic and little-known plants.

It is not surprising that during this phase of its history the garden introduced many innovations. Perhaps the oddest was its rockery, certainly one of the earliest, if not actually the earliest, to be built in Britain. Stanesby Alchorne, an otherwise undistinguished Director, acquired forty tons of old stones from the Tower of London; to these were added flints and chalk and a large quantity of

basaltic lava brought by Sir Joseph Banks from Iceland. The curious magpie colour scheme which resulted can still be seen by visitors and the rockery affords a home for numerous alpine plants.

The visit in 1682 of Dr Hermann, Professor of Botany at Leyden, was notable because it resulted in a formal exchange of seeds and plants between the two gardens; this is regarded as the beginning of the system of exchanges which now prevails among botanic gardens throughout the world. The current Chelsea list includes exchanges with about 250 stations, including, for example, thirty in Russia and five in China.

During the latter half of the nineteenth century the garden fell on hard times. The Society of Apothecaries ceased to find it so useful, perhaps because, with the rise of synthetic organic chemistry, drugs were no longer so exclusively a product of the plant kingdom. The garden was certainly a financial strain, and the Society alleged that it was no longer suitable for the purposes of a botanic garden, because of the deleterious effects of increasing atmospheric pollution in London and the impoverished state of the sandy soil. The Society asked to be relieved of its trust, but a Treasury Committee did not agree that the garden had outlived its usefulness. It satisfied itself that the garden was still well fitted for botanical purposes, a conclusion which has been fully justified. It also considered that the garden's advantages were likely to be highly appreciated by the students of the Royal College of Science (now part of Imperial College, London) and of the various London Polytechnics; in this opinion also, history has proved it right. In 1899 the Charity Commissioners appointed the Trustees of the London Parochial Charities trustees of the garden, with a committee of management consisting of their nominees and nominees of sundry learned and other bodies; financial support was provided by the City Parochial Foundation and the other organizations concerned. The trust laid it down that the charity should be 'administered exclusively for the promotion of the study of Botany', including 'instruction in Technical Pharmacology as far as the culture of medicinal plants is concerned'. The new managers erected a lecture room, laboratory, and Curator's house and installed heated greenhouses and pits. Outdoor beds were provided which supply the medicinal plants still widely needed for pharmacological teaching.

At the present time the garden serves botanical

education at every level and has users of every age. The Junior Naturalists Club is composed of London schoolchildren from eight years old to sixteen, who use the garden under direction on holidays and Saturdays. The importance of stimulating the interest of young people is now generally recognized, and it is interesting that four recent members of this club are at present undergraduates in university botany departments.

University extension courses and refresher courses for teachers make frequent use of the lecture room and the facilities of the garden itself. The most numerous users, directly or indirectly, are university and polytechnic students. Last year about four thousand visited the garden, and many more were indebted to it, perhaps unconsciously, for material with which they were working in their own colleges. Last year 30 000 specimens were provided for examination purposes alone, and as many as 80 000 have been sent out in the course of a year. As foreseen by the Treasury Committee in 1899, the closest association of the garden has been with the botany department of Imperial College, and almost daily supplies of materials are sent to it during term. The department's classes in systematic botany are carried on in the garden and its buildings, flowers held in deep freeze being used during the winter.

The longest association of all with Imperial College has, however, been on the side of research. Studies of plant growth, and particularly of its dependence on day-length and temperature—associated for so many years with the names of F. G. Gregory and O. N. Purvis—were all carried out in the garden and its laboratories. At the moment, investigations of growth, translocation, nitrogen metabolism, bacterial glands, and mosaic diseases are in progress. It is proper to add that in all its present activities the garden owes much to the enthusiasm and skill of the Director.

Two things particularly impress the botanical visitor to the garden. First of all, he feels that he has passed suddenly into another atmosphere and another century. The patina of the walls is of the eighteenth century, but it is in harmony with the laboratories erected in this century; in few other places can one be so conscious of a continuity of botanical history. Secondly, the visiting botanist can here carry on his taxonomic studies without the interruption from the general public that is unavoidable in some other botanic gardens. Once his bona fides is established, he can work without let or hindrance.

Internal fungal parasites of insects

M. F. MADELIN

Although fungi which grow on insects have long been studied, the special physiological characteristics associated with their entomogenous habit have been much neglected. As this article shows, such studies are far from purely academic. A greater knowledge of the behaviour and physiology of fungi parasitizing insects is essential for attempts to effect the control of insect pests by fungi, and may also suggest fresh approaches to the problem.

THE PARASITIC HABIT

Most of the fungi capable of growing on and killing insects are facultative parasites, that is, their growth is not strictly confined to living substrates. Nevertheless, many are difficult to grow in artificial culture, while others have yet to be cultivated apart from their normal living host. However, as they are closely allied to species that can be grown on artificial culture media, it is probable that they also will eventually be grown in this way. The very fact that they kill their hosts suggests, by analogy with plant pathogenic fungi, that their parasitism is not obligate. Among these fungi there is a wide variation in the degree of adaptation to the parasitic habit and in the importance of the parasitic phase in the life-cycle of the fungus. At one extreme lie most of the Entomophthorae and such lowly fungi as *Myiophagus* and *Coelomomyces*, which in nature are found only on insects; at the other are such species as *Aspergillus flavus* and *Mucor hiemalis*, for which parasitism on insects is certainly not essential to their normal life-cycle. Fungi like these, which are normally saprophytes of decaying organic matter, occasionally infect living insects for reasons which are at present imperfectly understood. Their assumption of the entomogenous habit can no doubt be attributed to their acquisition of a full complement of pathogenic characteristics, which include the opportunity to contact the insect, and the ability to penetrate, colonize, and kill it. Sometimes the changed habit may result simply from a fortuitous meeting of fungus and insect, but it is probable that it is often due to the acquisition of an appropriate physiological characteristic by genetical change in the fungus.

INFECTION OF THE INSECT HOST

Fungi infect insects either through the outer integument or through the walls of the digestive tract. The integument is a complex structure,

composed of a continuous layer of epidermal cells overlaid with cuticle. The outermost layer of this is the epicuticle, which may itself contain several layers, of which one usually consists of wax. Beneath the epicuticle is the procuticle: this is a solid layer of protein and chitin; these may be linked chemically. Chitin is a macromolecular polymer of N-acetyl glucosamine units joined by β -glycosidic linkages: structurally it closely resembles cellulose. The continuity of the outer boundary layer of the insect is interrupted by stigmata, the outer openings of the tracheae by which respiration is effected, which are lined with a thinner chitinous cuticle. The digestive tract is composed of three major parts, of which two—the fore- and hind-guts—are similarly lined by a chitinous cuticle; this substance is not present in the mid-gut.

Fungal germ-tubes able to penetrate the outer integument of the host insect have been reported: for example, for *A. flavus* [1, 2], *A. fumigatus* [2], and *Beauveria bassiana* [3]. Entomogenous members of the Entomophthorae are believed generally to infect through the integument, and G. Schweizer [4] has illustrated germ-tubes of *Empusa muscae* entering a fly by this route. There is, however, little information about the precise means by which penetration is accomplished.

The wax layer in the epicuticle undoubtedly prevents many fungi from entering the body. A. S. Sussman [5] found that by dewaxing the pupae of *Platysamia cecropia* with ether he removed their resistance to infection by *A. flavus* through the integument. Similarly, K. Koidsumi [6] found that larvae of silkworms (*Bombyx mori*) and of *Chilo simplex* became highly susceptible to *A. flavus* and other fungi when their epicuticular lipids were removed. The antifungal action of the extractable lipids was attributed chiefly to free medium-chain saturated fatty acids (presumably caprylic or capric) which occur in the cuticle.

Many plant pathogenic fungi encounter a similar barrier to penetration in the waxy cuticle which overlies the epidermis of the plant shoot. It appears that no fungi are able to digest plant cuticle enzymically, the penetration by germ-tubes being by mechanical means. It is possible that the waxy epicuticle of insects is also penetrated mechanically, although the movements of insects may well abrade it sufficiently for fungi to enter. Abrasion is known greatly to reduce resistance due to this layer [6].

In 1934 C. L. Lefebvre [3] suggested, from his own observations, that penetration of the chitinous procuticle was by enzymic softening and solution, accompanied by mechanical pressure. However, it is only recently that chitinase activity has been directly demonstrated in entomogenous fungi. J. Huber [7] found that the four common parasites, *A. flavus*, *B. bassiana*, *Cordyceps militaris*, and *Metarrhizium anisopliae*, could all hydrolyse chitin to N-acetyl glucosamine, but he was unable to detect D-glucosamine, which is also formed when chitin is decomposed by bacteria.

Instead of directly penetrating the integument, some fungi appear to enter via the stigmata. P. Lepesme [8] found that *A. flavus* could not infect the desert locust (*Schistocerca gregaria*) from the outside if the stigmata were plugged with cotton wool. He also found that infection occurred more readily through thoracic than through abdominal stigmata. As air chiefly enters by the thoracic stigmata and escapes through the abdominal ones, this suggested a simple explanation, but its inadequacy was revealed by Lepesme's discovery of fungal spores within abdominal tracheae of naturally contaminated insects. Further, the natural or artificial introduction of spores into abdominal tracheae only exceptionally led to disease. He thus concluded that the muscular tissues of the thorax must have favoured the growth of those spores which entered the thoracic stigmata. C. E. Burnside [2] found that spores of *A. flavus* seemed unable to germinate in the tracheae of the honey bee, and attributed it to their dryness, the result of constant aeration.

Successful infection through the integument of an insect above the ground requires microclimatic conditions similar to those for infection of plants by fungi, namely a favourable temperature and a high humidity maintained long enough to enable the germ-tube to enter the host. Infection by the chytrid *Myiophagus ucrainicus*, which attacks scale and other insects, actually requires the presence of free water in which the flagellate infective spores

can swim. By contrast, the infective unit of some entomogenous fungi, particularly those in which the infected insect is found in the soil, is possibly not a spore but vegetative mycelium. *Isaria farinosa* (figure 1), whose tufted white fructifications arising from infected Lepidopterous pupae buried in the soil are common in autumn, may be an example. In autumn, when it produces large numbers of spores, there are few suitable larvae in a position to become infected by them. It remains to be established whether the spores themselves persist until larvae again become abundant, or whether they give rise to saprophytic mycelium which later infects them directly or after further sporulation.

Infection commonly takes place through the walls of the digestive tract, often in addition to infection through the integument. Thus *A. flavus* and *B. bassiana* have been observed to infect insects in both ways, and it is probable that *Sorospora wella* does so as well [9]. Infection via the gut depends upon rather special conditions. The spore must remain viable in the presence of the digestive juices of the insect; it must be able to germinate under the physical and chemical conditions prevailing in at least some part of the intestine, and its germ-tube must be able to penetrate the gut wall. It will not be directly affected by external humidity. Conditions in the gut differ in different parts. For example, in the fore-gut the pH is largely dependent on that of the insect's food. In the mid-gut, it varies between pH 3 and pH 10 according to the species, and in an individual insect even varies in different parts of the mid-gut. In the hind-gut, variation in pH rarely approaches the extremes encountered in the mid-gut. One may therefore expect the fungus to be rather specific in its site of infection, but little information is available. Sussman [1] observed that *A. flavus* entered through the hind-gut of *P. cecropia*.

Burnside [2] concluded that the pathogenicity of fungi which attack bees through the gut wall appears to be determined by the ability of their spores and mycelia to resist the action of the intestinal fluids. He found that only spores from old cultures of a particular isolate of *A. ochraceus* could infect bees through the gut. As the spores aged, their walls became thicker and more hardened, changes which he considered increased their resistance to digestive juices. He suggested that after germination, the digestive fluids of the bees had no effect on the young mycelium. An alternative explanation is that the spores, before

they germinated, had passed the region of the gut where their viability was threatened.

Penetration and closely associated stages of infection sometimes lead immediately to local symptoms. Frequently the reaction is not specific for the invading fungus, and involves the production of black pigment [1, 10, 11]. There may be additional local reactions by the living tissues. In *Galleria mellonella* the hypodermis often becomes separated from the overlying procuticle, and in the space thus formed, blood cells accumulate as a sort of abscess [10]. In Colorado beetle larvae, an area infected with *M. anisopliae* swells like a boil, owing to the formation of a cushion of mycelium in the body wall; this cushion may become so large that the overlying cuticle ruptures [11].

COLONIZATION OF THE INFECTED HOST

There are two main ways in which the penetrating fungus colonizes the host. One is by simple mycelial growth, and the other is by the separation of isolated cells, variously called conidia, cylindergonidia, hyphal bodies, or blastocysts. These cells circulate in the blood, either multiplying there or being conveyed in it to various sites of secondary internal infection. In some fungi, the multiplication of such cells sooner or later gives way to the formation of hyphae, while in others these cells give rise to sporogenous filaments, or themselves change into spores. *A. flavus* appears always to invade as mycelium [1, 2, 8, see figure 2]; *M. anisopliae* can colonize by both methods; while *Saccharomyces* spp. [2], *S. uwelli* [9], *Entomophthora fumosa* [12], and a number of *Empusa* species [13] all produce cells that circulate in the blood.

In colonizing its host, the fungus usually shows a definite pattern of distribution and abundance in different sorts of tissue. Sometimes the blood is the site of abundant proliferation, particularly in those fungi in which the free cell is an important stage in the life-cycle; examples are *Saccharomyces* spp., *S. uwelli*, and certain *Empusa* and *Entomophthora* species. *E. fumosa* [12] and a number of pathogenic yeasts [2] may produce so many free cells in the blood that it becomes milky. Cells of this sort may produce substances, presumably enzymes, which cause the breakdown of other tissues [9]. In other fungi the free-cell stage is less well developed, and possibly represents a somewhat casual invasion of a more or less amenable environment, or it may represent a phase in the internal dissemination of the pathogen.

Distribution of a pathogen by the circulation of the blood is passive. It is in hyphal invasion that a positive preference for certain sorts of tissue is

commonly manifested. In the Entomophthoreae there is frequently an early attack on, and proliferation in, the fat-body. For example, penetrating germ-tubes of *Empusa muscae* grow directly towards the fatty tissues of the common house fly, and in artificial culture show a similar response to the presence of fat [4]. *A. flavus* on larvae of *P. cecropia* [1] and *B. bassiana* on those of *Pyrausta nubilalis* [3] likewise make an early attack on the fat-body. After invading the fat-body, *B. bassiana* next attacks the silk glands and Malpighian tubules, then the chitinous linings of fore- and hind-guts; only after this does it attack the muscles, nervous system, and gonads. By contrast, *A. flavus* was never seen anywhere in diseased, but still living, adult desert locusts (*S. gregaria*) except in the muscles, and attempts to grow it on excised fatty tissues failed [8]. This effect can probably be attributed to a component of the fatty tissues other than the fat, glycogen, and protein known to abound there. Similarly, pathogenic yeasts injected into adult honey-bees develop most abundantly on the muscle fibres in the thorax, where, while bathed in the flow of blood, they multiply without altering their position [2]. Here, however, the distribution of the pathogen is governed more by the host's anatomy than by the predilections of the fungus. In living house-flies, and living larvae of Colorado beetle, infected with *M. anisopliae*, the fungus is confined to parts of the body wall and to the blood. Only after the death of the host are the nervous system, muscle fibres, and fat-body penetrated and consumed [11]. It is important to distinguish between parasitic and saprophytic phases of colonization, for otherwise the occurrence of vital resistance in particular tissues and organs may remain undetected.

A physical barrier may influence the course of infection. The male adult cicada *Tibicina septendecim* contains an empty sac in the anterior part of the abdomen, and a portion of this sac forms a transverse septum across the body cavity. The fungus *Massospora cicadina* (Entomophthoreae) which attacks this cicada develops only on the genitalia and organs lying posterior to this septum, and there forms its conidia. When infection ultimately results in the production of resting spores, the septum is destroyed by the preceding vegetative mycelium, and the spore mass then arises in the otherwise empty anterior portion of the abdomen [14].

PRODUCTION OF SYMPTOMS OF DISEASE

The attack of the fungus results in the production

of a number of symptoms which are sometimes characteristic for the disease. However, some symptoms are common to a variety of fungus diseases and hosts. They include changes in the behaviour, internal structure, colour, and physiology of the insect. Various symptoms may occur in a single insect simultaneously or consecutively, and undoubtedly are sometimes closely interrelated.

One of the commonest behavioural symptoms, and usually the first to be manifested, is loss of appetite, and this is often accompanied by a restlessness which causes the insect to wander away from its source of food [15]. Honey bees infected with *Aspergillus* continually try to escape from the clusters of healthy bees, and continue to move when the rest of the bees in the colony are quiet [2]. This restlessness frequently leads ailing insects to ascend plant stems and foliage, where their eventual death in such positions places the pathogens in situations very well suited to efficient dispersal of their spores [15, 16]. The movements of diseased insects are usually weak and rather unco-ordinated [1, 2, 9, 12]: this may be the result of partial paralysis. *A. flavus* may paralyse only one part or side of honey bees and desert locusts, so that certain limbs become useless [2, 8]. In the bee, this paralysis is associated with enzymic softening of the muscles. In addition a toxin is formed, demonstrable *in vitro*, which produces visible symptoms in bees within four hours of its being ingested, and kills within ten hours [2]. Lepesme [8] attributed the paralysis of locusts by *A. flavus* to the physical presence of the fungus in the muscles, but there, too, the muscles eventually became changed to a brownish pulp. *B. bassiana* also paralyzes, sometimes, at least, very rapidly, the insects that it attacks. E. Dresner [17] found that adult house flies dusted with its spores and maintained at 100 per cent relative humidity became paralysed in from half to three hours: it is presumed that a toxin had diffused into the insects' bodies.

Colour changes in the infected insect are of various sorts. Some are caused by the colour of the fungus itself or by pigments which it produces, and some are the result of melanin reactions. Noctuid larvae infected with *S. uvella* turn creamy white one or two days before death, and if they are pricked, the blood that flows out is white because of the abundance of free cells of the parasite. Reddish-brown patches, which sometimes appear shortly before death, are caused by the presence of similarly coloured resting spores

[9]. In the same way, resting spores of *Coelomomyces spp.* colour infected mosquito-larvae a rusty brown. The ochraceous spots which appear on the thorax of adult desert locusts infected with *A. flavus* are attributed by Lepesme [8] to a yellow pigment secreted by the fungus, the mycelium of which corresponds in its distribution to that of the spots. This fungus also gives rise to the production of melanin granules in the thorax of the locust, and causes a melanin reaction in the blood of larvae of *P. cecropia*. Although this reaction can be inhibited in diseased animals by copper-chelating compounds, death still occurs [18]. Larvae of *Malacosoma spp.* infected with *Empusa megasperma* turn brown or black, and in three species the diseased insects contain quantities of yellow crystals of unknown composition [13]. By contrast, *Empusa planchoniana* causes certain aphids to change from their normal black to a brick-red colour.

Sussman [19] studied some of the physiological changes associated with the attack of *A. flavus* on pupae of *P. cecropia* and found that the amount of oxygen used by the pupae and the fungus rose steeply during the first few days of the infection. The rate at which weight was lost in infected pupae was about seven times greater than in healthy pupae.

OPPOSITION TO FUNGAL INVASION

The defensive property of the cuticle has already been mentioned. Its importance is indicated by the fact that a number of fungi that rarely or never parasitize insects can readily kill them if injected directly into the body cavity [2, 10]. The blood, however, presents a further defence, for spores or free fungal cells in it are commonly subject to attempts by phagocytes to ingest and destroy them. A. T. Speare [9] found that cells of *S. uvella* were either not ingested by blood cells of susceptible hosts or, if they were, survived ingestion. By contrast, the fungus did not survive in the blood of resistant insects unless introduced in such large numbers that the phagocytes were apparently unable to deal with them. When spores of the pathogenic fungus *A. flavus* and of the innocuous *A. niger* were injected into larvae of *P. cecropia* the phagocytes ingested more spores of *A. niger* than of the pathogen. However, even the surviving spores of *A. niger* failed to germinate, which suggested the presence of substances inhibitory to this species [1]. Spores of *A. luchuensis* injected into the body cavity of *P. cecropia* occasionally failed to develop further because they

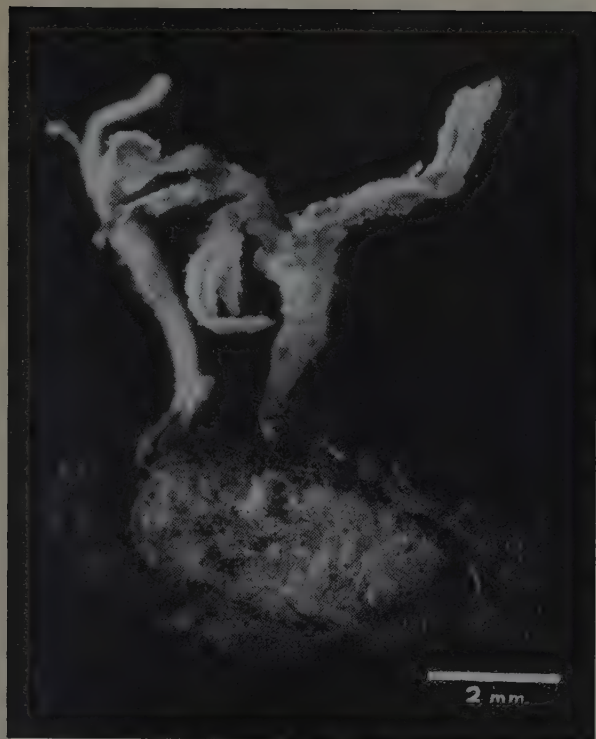


FIGURE 1—Fructifications of *I. farinosa* on a dead infected lepidopterous pupa.

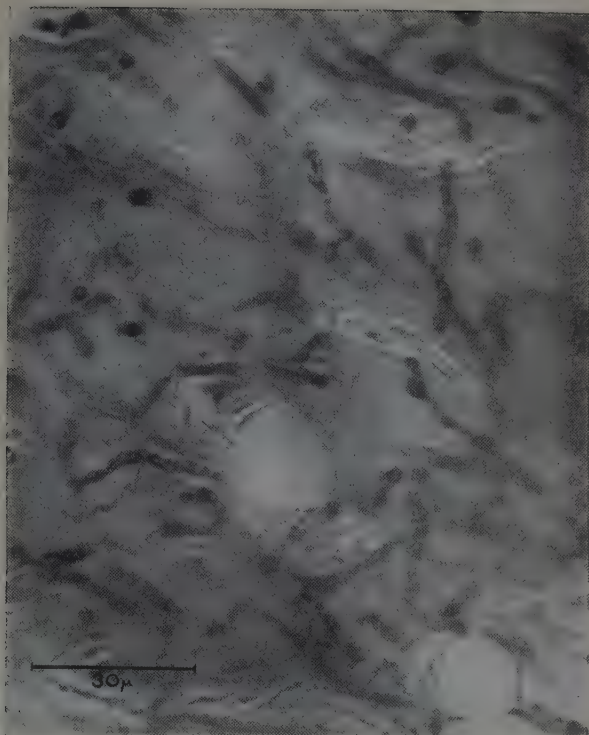


FIGURE 2—Mycelium of *A. flavus* in the wing muscles of a locust (*S. gregaria*) at the time of death.

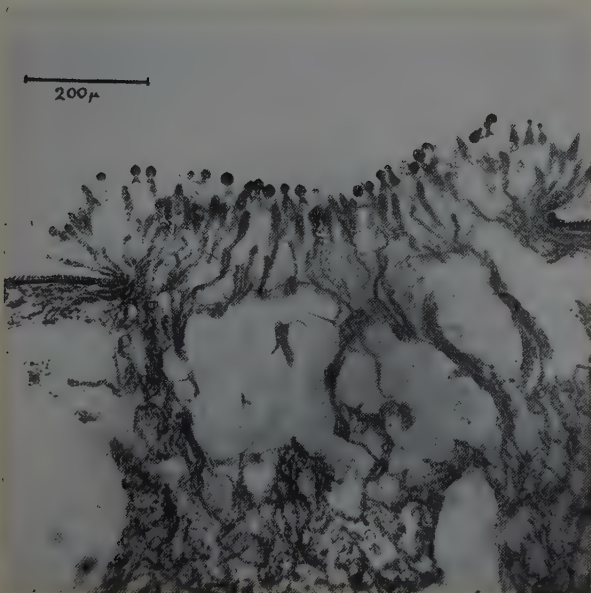


FIGURE 3—Longitudinal section of the abdomen of a fly killed by *E. muscae*, showing the emergence of sporangiophores through the ruptured intersegmental membrane.

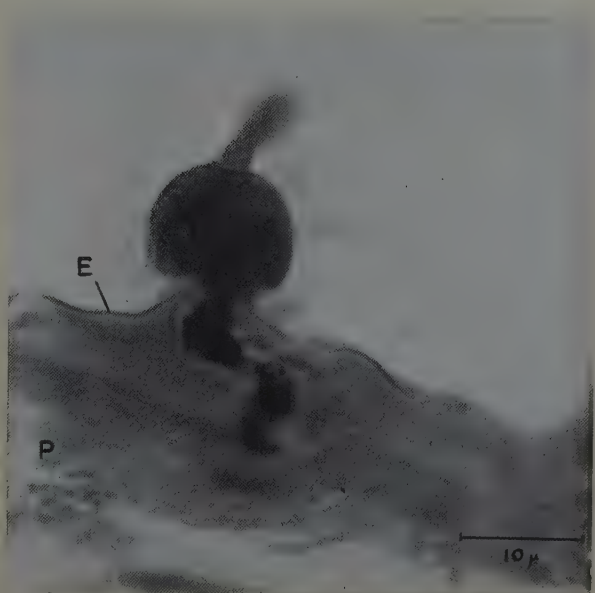


FIGURE 4—Pre-mortem emergence of single hypha of *A. flavus* through the thoracic integument of a locust. The hypha swelled both before and after penetrating the epicuticle (*E*). (*P*, chitinous procuticle.)



FIGURE 5—Adult desert locust (*S. gregaria*) two days after death caused by *A. flavus*. Hyphae have emerged through the articulating membranes at the base of the hind leg and have produced a pustule of spores (S).

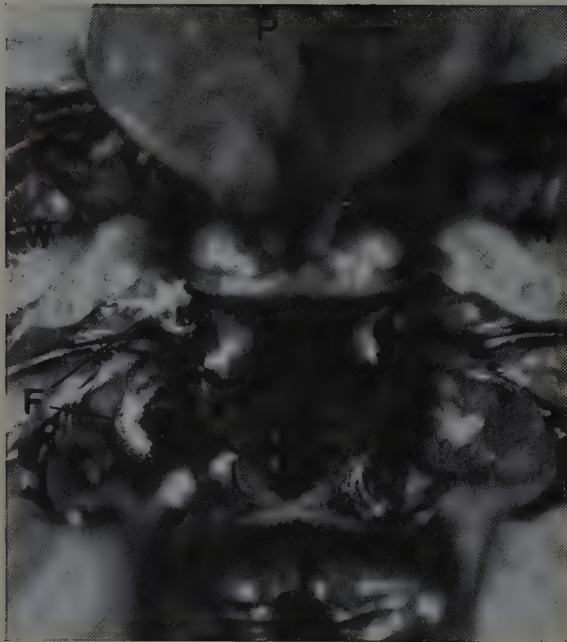


FIGURE 6—Dorsal surface of thorax of diseased adult locust with wings outstretched, showing pre-mortem emergence of hyphae of *A. flavus* through the articulating membranes at the wing roots. (W, wing; P, pronotum; F, fungus.)

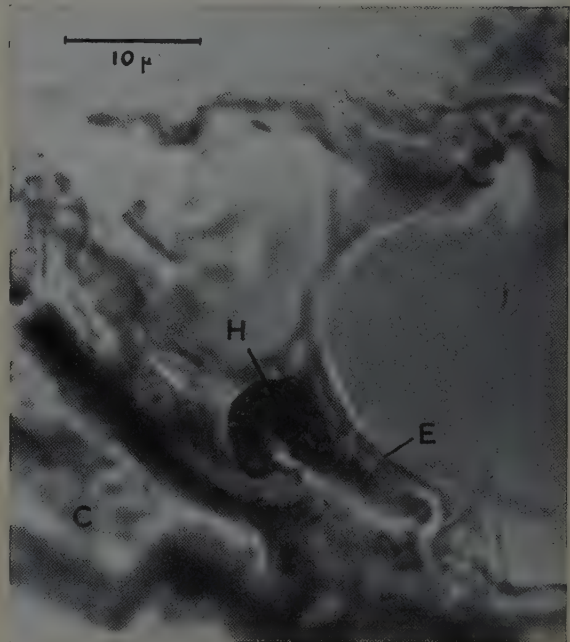


FIGURE 7—Section through an acute fold of the articulating membrane at the wing root of the locust illustrated in figure 6. Mycelium permeates the chitinous procuticle (C) but appears to be restrained from emerging by the thin epicuticle (E), which has affected the shape of one hypha (H).

became isolated by blood cells and epithelium, but the more virulent *A. flavus* spores encountered this check less frequently [5]. Fungal spores introduced into caterpillars of *G. mellonella* may be enveloped by giant cells in a rather similar manner [10].

PRE-MORTEM BEHAVIOUR OF THE FUNGUS

While the diseased insect remains alive, the parasitic fungus is usually wholly vegetative. However, some fungi on some hosts commence to sporulate before the hosts are dead, as may happen with *S. uella* on cutworms [9]. The most striking example is that of *M. cicadina* on *T. septendecim*, in the adults of which it produces conidia or resting spores in large masses in the abdomen of the still-living host. The fungus attacks the intersegmental membranes of the abdomen so that the hind segments progressively fall away to expose a pustule of spores which are scattered as the dying insect crawls or flies about [14]. Possibly allied to *M. cicadina* is *Zygaenobia intestinalis*, which infects the mid-gut epithelium of larvae of *Zygaena carniolica* and discharges conidia into the gut, to be distributed with the faeces.

Besides pre-mortem sporulation, fungal hyphae may actually emerge from the host while it still lives (see figure 6). R. Thaxter [15] saw an adult geometrid moth fluttering to free itself from a pine needle, to which it was attached by rhizoids of *Empusa geometralis* that had emerged from its abdomen.

DEATH OF THE INSECT HOST

The time between infection and death depends on the fungus, the insect, and the prevailing conditions, but commonly it is between two and seven days, though sometimes longer. Although it is unlikely that any single mode of action of the fungal parasite is alone responsible for the death of the insect, a number of workers have ascribed important lethal roles to particular factors, which include histolysis by secretions, presumably enzymes [2, 8, 9]; destruction of blood cells [11]; production of toxins [2]; and mechanical action [2]. Sussman [19] suggests that one of the ways by which *A. flavus* kills pupae of *P. cecropia* is by interference with the functioning of the insects' tracheoles and spiracles, either directly or by destroying the nervous system. Tracheoles and ganglia are known to be attacked by this pathogen.

It is clear that many factors may individually cause or contribute to the death of the host. The important factors that govern the degree of pathogenicity of the fungus are those which will

convert the insect to a morphological or physiological state at which its premature death becomes inevitable. Immediately pre-mortem and, naturally, all post-mortem actions of the fungus are of little consequence in this respect.

POST-MORTEM BEHAVIOUR OF THE FUNGUS

Post-mortem behaviour of the fungus is mycologically interesting and epidemiologically important, since it concerns the provision made by the fungus for production and dissemination of spores. Some provision for spore dispersal often arises even before death when the dying insect climbs to an elevated position; there it dies, attached to its support by the grip of its paralysed limbs or by hyphae which may have erupted from its body.

Basically, there are three post-mortem phases which involve both insect and fungus. Firstly, the now saprophytic fungus completes the colonization and digestion of the dead insect as far as it is able. Secondly, the fungus emerges through the integument, which generally persists after the soft internal tissues have been digested. Thirdly, the emergent mycelium produces the reproductive structures of the fungus. This sequence is normally encountered where conditions are suitable for the spread of the pathogen in an insect population, but the fungus sometimes produces resting instead of infective spores, and these may then be retained within the body of the host.

Although the body of the host sometimes becomes limp and flaccid during the parasitic phase of a mycosis [1, 9], an increase in firmness after death is a common phenomenon, and is sometimes caused simply by the presence of the fungus itself [2]. Most *Cordyceps* species and also *I. farinosa* mummify their hosts, so that essentially they become fungal sclerotia contained in their hosts' persistent integuments. However, it sometimes happens that the interior of the killed insect liquefies and the fungus fails to sporulate. This is due to the histolysis of the killed host by secondary organisms, chiefly bacteria from its intestinal flora [2, 17].

The emergence of the fungus entails penetration of the chitinous cuticle, usually a task which has already been accomplished once during entry of the fungus into the host. Such penetration usually takes place by way of the intersegmental membranes [2, 8, 11; see figures 3 and 5]. The fact that individual hyphae are involved in at least the early stages of penetration suggests that fungal chitinase plays a part in this process (see figures 4 and 7). Sometimes the fungus avails itself of other

weak points in the integument, such as stigmata, pores of wax glands, and the points of insertion of scales. Once outside the host, the mycelium may give rise to conidiophores more or less directly, as happens in a number of the Entomophthorae, or it may undergo a certain amount of development outside the host to form either a loose or compact layer over the surface of the host. It may also grow perpendicular to the host's surface as a tuft of fertile hyphae or as a compact fructification, as in species of *Cordyceps*.

The spores produced on the outside of the host are those usually responsible for the dissemination of the disease. However, many fungi, particularly Phycomycetes, also produce resting spores inside the host. In a very few *Empusa* and *Entomophthora* species, resting spores are formed on external mycelium [13, 15]. How the spores are dispersed is fairly readily observed or inferred, but what ultimately happens to them is often a matter for conjecture. The infection-chains of many insect mycoses studied in the laboratory have, under these conditions, been very simple, but represent only a part of the chain that occurs in nature. Natural infection-chains are undoubtedly more complex, since they include the survival of the fungus through adverse periods, but unfortunately there is little detailed information about these. The length of time that spores remain alive is important in this connection. In the Entomophthorae the conidia remain viable for only a short time, those of *E. muscae* losing their ability to germinate in three to five days [4]. However, the conidia of *B. bassiana* and *Metarrhizium* remain viable for more than a year [10]. Resting spores usually receive no special provision for dissemination: those of *M. cicadina* are exceptional [14]. In most of the Entomophthorae they lie within the body of the dead host, and most attempts to germinate them have failed [13, 15]. However, Schweizer [4] found that the resting spores of *E. muscae* require a certain pretreatment before they become germinable. In nature this property is acquired during the winter, but in the laboratory it may be induced by exposing resting spores to the action of chitin-consuming bacteria, such as in nature contribute to the decay of the exoskeleton of the host. After this treatment the formerly chitinous spore-wall is much swollen and gummy, and no longer responds positively to tests for chitin; the spore is now germinable. By contrast, the resting spores of *S. uwelli* are capable of germinating immediately after their formation, yet also of remaining viable for at least fourteen months under dry conditions [9].

NATURAL GROWTH ON SUBSTRATES OTHER THAN INSECTS

The nutritional requirements of many entomogenous fungi are complex, and it therefore appears unlikely that such fungi ever find conditions in nature that enable them to grow other than on their normal hosts. *Entomophthora coronata* (*Conidiobolus villosus*) appears to be the only entomophagous member of the Entomophthorae that has been found growing in nature on a substrate other than an insect's body. However, many less specialized entomogenous fungi, such as *Aspergillus* spp. [2, 8, 20], are known to occur naturally on other substrates. For such fungi a resumption of saprophytism may be an important mode of survival where specially resistant structures are lacking from the life-cycle. It is generally believed that *I. farinosa*, *B. bassiana*, and *M. anisopliae* can survive in the soil, even if they do not actually grow there. J. Huber [7] found that the latter two species, as well as *C. militaris* and *A. flavus*, were prevented from growing by micro-organisms present in certain soils, but it does not necessarily follow that such conditions exist in all soils. More information is needed on the ecology of soil-inhabiting entomogenous fungi (see [16]).

PHYSIOLOGICAL CHARACTERISTICS OF ENTOMOGENOUS FUNGI

Although inability to enter the insect body prevents some fungi from being pathogenic, it is certainly not the sole factor, for certain species of *Penicillium* [20] and *Aspergillus niger* [1] do not kill pupae of *P. cecropia* even when injected. Of twenty species of *Aspergillus* injected into these pupae only six were lethal, being chiefly in the *A. flavus-oryzae* group. However, entomogenous species are known in eleven of the fourteen groups in this genus [20].

Present knowledge of the physiological characteristics of entomogenous fungi does not allow a very close correlation between these and their pathogenicity. Concerning their digestive powers, extracellular hydrolysis of fats has been demonstrated in artificial culture in *A. flavus*, *B. bassiana*, *C. militaris*, *M. anisopliae* [7], and *E. muscae* [4]. Proteolytic activity exists in *B. bassiana*, *C. militaris* [7], *A. flavus* [2, 7], *A. effusus*, *A. fumigatus* [2], and in several of the Entomophthorae. Glycogenase activity is shown by *M. anisopliae* [7]. Chitinase is formed by *A. flavus*, *B. bassiana*, *C. militaris*, and *M. anisopliae*, although the presence of adequate amounts of readily used carbon and nitrogen suppresses the digestion of chitin by these fungi

[7]. Clearly the available data relate to only a small number of entomogenous species, but they include species of widespread occurrence, some of which are perhaps the commonest and generally most destructive to insect populations. Extracellular chitinase, lipase, protease, and glycogenase activities are thus known in entomogenous fungi, and are clearly related to the gross composition of the insect as a nutritive substrate.

There appears to be no correlation between the quantitative production of protease by *Aspergillus* species and their virulence [2]. While Huber [7] found that quantitative differences do exist between the abilities of *A. flavus*, *B. bassiana*, *C. militaris*, and *M. anisopliae* to decompose fats, glycogen, proteins, and urea, these differences have not been correlated with degrees of pathogenicity. He suggested that chitin digestion by his isolates of *A. flavus* and *M. anisopliae* was more vigorous than that by *B. bassiana* and *C. militaris* because of the shorter time that the two former fungi had been held in artificial culture. It has also been a matter of common experience that entomogenous fungi decline in virulence after prolonged artificial culture, though exceptions have been reported. Conversely, the virulence of *A. flavus* towards locusts can be increased by successive passages through susceptible hosts [8]. It might, therefore, prove possible to correlate these changes with changed digestive powers.

Entomogenous fungi show widely differing degrees of host specificity. Some of the commonest species, such as *Beauveria spp.*, *M. anisopliae*, and *Aspergillus spp.*, are in fact common because they infect so many different sorts of insect. Of greater interest physiologically are those fungi which show a high degree of host specificity. D. M. MacLeod [21] found that while fungi such as *B. bassiana*, *I. farinosa*, and *M. anisopliae*, which have a simple nutritional requirement, are associated with a variety of insect species, those with more exacting requirements, such as certain species of *Spicaria* and *Hirsutella*, appear to be limited each to a particular host species. Huber similarly found [7] that *Pericystis apis* has a very specialized nutritional requirement, which is manifestly correlated with its restriction to a single host, the bee: a constituent of skim milk or of yeast extract meets this need. He was unable to establish any correlation between ability to use different carbohydrates and host specificity in this and a number of other species. Among the entomogenous Phycomycetes, *Entomophthora apiculata* has simple nutritional requirements for at least its

vegetative growth [22], and is found on three different orders of insect [15]. By contrast, *E. muscae*, which for its normal and complete development in artificial culture requires certain thermo-labile materials as well as fat [4], has been found only on certain members of the Diptera.

It is unlikely that the sole basis of host specificity is a nutritional one, for such a factor could operate only after the fungus has penetrated the insect's integument. Koidsumi's demonstration of antifungal lipids in insect cuticles [6] suggests another sort of basis. Differences in the content of antifungal materials in the cuticles of different insect species, and differences in the sensitivity of fungi to such substances, may govern particular host-parasite combinations. Another contributory factor may be the existence of different degrees of susceptibility to phagocytic and humoral defences in the blood of the host. Host-range must also be influenced by opportunity, since the fungus must make physical contact with the insect before infection can occur. The rarity of mycoses in cerambycids is believed to be related to the isolation of the immature stages of the insects within the wood of the host plant during development [23].

It is likely that factors similar to those which control host specificity are also the basis of the commonly observed changes in susceptibility which occur at different stages in the development of the insect. From egg to adult it passes through stages differing much in form, habit, and physiology, and the changes are evidently such that they sometimes create or destroy the conditions in which particular pathogens are able to infect.

ECONOMIC ASPECTS OF ENTOMOGENOUS FUNGI

Many attempts have been made to employ fungus diseases of insects for pest control, but comparatively few have been wholly successful [24]. That the method has value, however, has been demonstrated by such examples as the control of two apple pests in Nova Scotia in the 1920s by artificial dissemination of species of *Empusa* and *Entomophthora*. The reasons for the many failures, where ascertainable, are several, but important among them is the fact that many investigators failed fully to appreciate the factors and principles involved. To be successful, control entails the creation of an epidemic in a population. Since mortality from a contagious disease in a population depends on its density, an insect must be fairly densely distributed if biological control is to

be successful. A humid climate is also generally necessary. Many workers, too, failed to distinguish clearly between the two main ways in which parasitic fungi may be employed: as insecticides for the immediate destruction of insect populations, or as long-term biological agents to reduce host populations to lower levels [25]. Total destruction of a pest population is virtually impossible by biological control, and this appears to be one reason for many of the earlier attempts being abandoned in favour of the use of chemical insecticides. However, as a means of reducing the level of an insect population the prime requirement of the fungus is that it should persist as a controlling factor; provided it can remain active in populations of the pest sufficiently sparse to be tolerable economically, its utilization should prove practicable. The use of microbial control agents in the future is most likely to succeed on crops where the cost of a little damage by the pest can be withstood [25].

Biological control of insects by fungi has many limitations [24], but against these may be set many advantages such as specificity of action and a high degree of permanence. Absence of toxic residues is a further advantage which may make it an increasingly attractive proposition in favourable conditions.

Naturally occurring entomogenous fungi com-

monly exercise a large degree of control over various insect pests, particularly in warm, humid climates. The importance of these fungi must be considered if undesirable consequences of using fungicidal sprays are to be averted. There are many records of insect populations increasing after the use of such sprays, as for example on *Citrus* in Florida, believed to be a result of the destruction of the fungi that normally restrict them.

Entomogenous fungi are also economically important because of the damage they do to useful insects. They are, for example, a danger to honey bees and silkworms.

CONCLUSION

The term 'entomogenous fungus' embraces the secondary parasite and the saprophyte as well as the true parasite. It is important to distinguish these forms in studies on entomogenous fungi, and similarly to differentiate the parasitic and saprophytic phases of the attack of a particular fungus on an individual insect. A great deal of variation in virulence clearly exists between different species and strains of parasitic fungi, but the precise nature of these differences and their causes remains to be established. The natural infection-chains of many common parasites also need to be studied. Information on these topics might have very considerable practical importance.

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Zone refining

E. F. G. HERINGTON

Zone refining is a process in which a rod of impure material is purified by heating it so as to cause a molten zone to pass along its length: it was originally developed for preparing germanium for transistors. Subsequently the technique, which has in certain applications marked advantages over both distillation and chromatography for the production of a virtually pure material, has been applied to a wide variety of substances. This article describes the theory of zone refining, the apparatus used, and some of its applications.

INTRODUCTION

The modern technique of zone refining dates from W. G. Pfann's discovery, in 1952 [1], of the effect of passing a rod of germanium through a short furnace so that a molten zone moves along the specimen (figure 1). He found that impurities tend to be carried forward in the molten zone: by repeating the process a number of times, a high

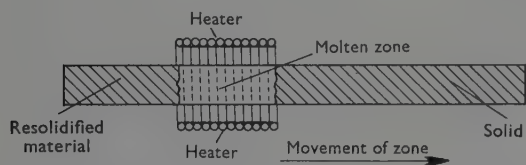


FIGURE 1 - Diagrammatic representation of a zone-refining experiment.

degree of purification was achieved—in some experiments the impurity concentration in a large part of the rod was reduced to one part in 10^9 . The technique, originally developed for the manufacture of material for transistors, has since been used for a wide range of metals and also for both inorganic and organic compounds. This article is concerned with the basic theory of the process and with some of its applications.

PRINCIPLES OF ZONE REFINING

When a liquid mixture is cooled, the solid that crystallizes out usually has a composition different from that of the liquid: the purification of substances by zone refining depends on this difference. A study of two simple types of solid-liquid equilibrium reveals some of the conditions that arise during zone refining. In a system whose phase diagram is of the type shown in figure 2, the cooling of liquid of composition J will cause crystallization of pure component A when the temperature corresponding to point L is reached; if the original composition corresponds instead to

point J_1 , the first solid to separate will be pure component B.

The behaviour of a mixture that forms a series of solid solutions is shown in figure 5. Here, solid of composition N separates when liquid of composition J cools. This solid is richer in component A than the liquid from which it came, but still contains component B: if the original composition corresponds instead to point J_1 , then the solid first deposited will have composition N_1 . The solid is thus richer in component A than the liquid from which it has been deposited, whatever the initial composition of the liquid.

In discussing the zone refining of mixtures with phase diagrams such as figure 5, it is convenient to define an 'ideal distribution coefficient' (k_1) as the ratio of the percentage of impurity in the solid that is crystallizing to that in the liquid with which it is in equilibrium. When the original composition is J, $k_1 = MN/ML$; when the original composition

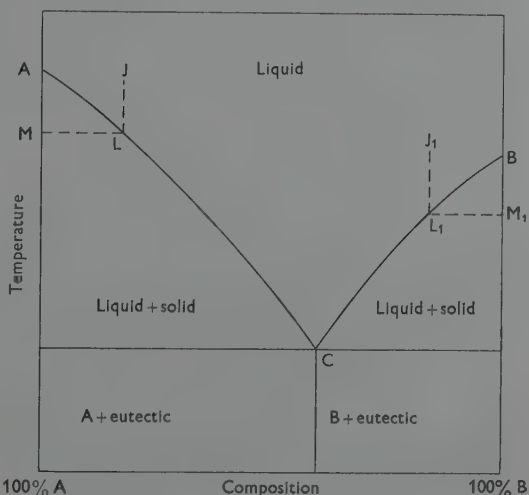


FIGURE 2 - Phase diagram for a system exhibiting a simple eutectic.



FIGURE 3 — Apparatus for the purification of organic compounds. Note the narrow black line of insoluble impurity near the bottom. (Crown copyright reserved.)

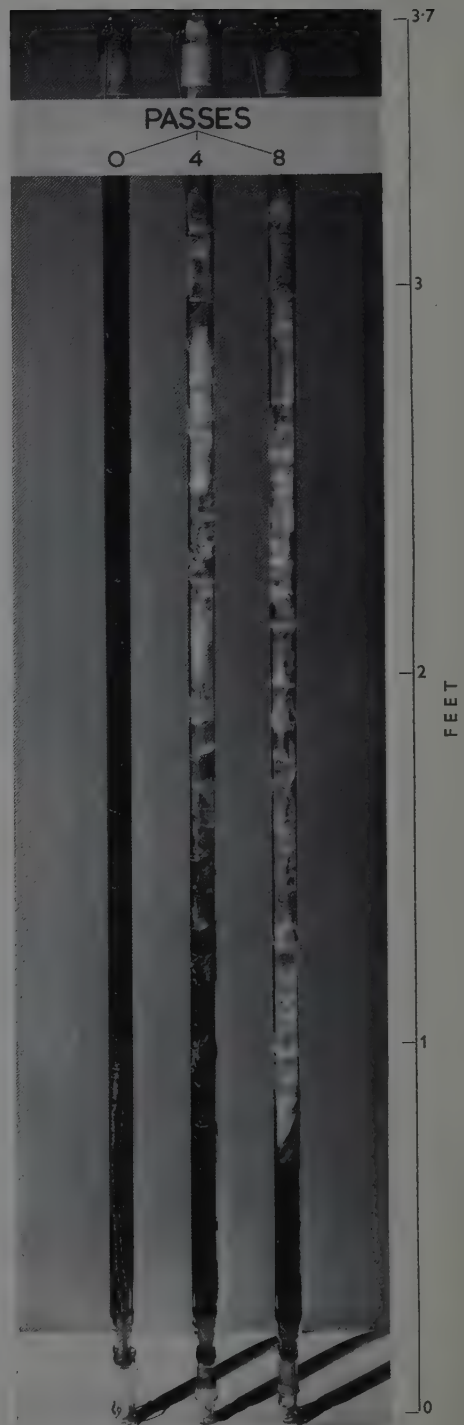


FIGURE 4 — The tube on the left was filled with a solid solution of 0.03 per cent induline in naphthalene. The centre tube and that on the right were obtained after the passage of four and eight zones respectively. (Crown copyright reserved.)

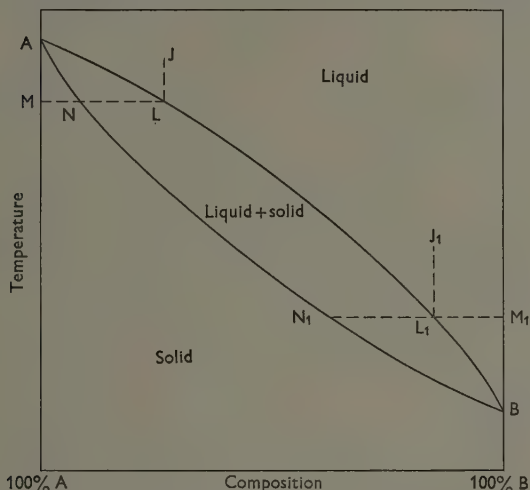


FIGURE 5 — Phase diagram for a system exhibiting a series of solid solutions.

is J_1 , $k_i = M_1 N_1 / M_1 L_1$. The value of k_i is thus less than unity for composition J and greater than unity for composition J_1 . The same definition of k_i can be adopted for systems represented by figure 2, if N is regarded as coinciding with M in that figure. In such systems $k_i = 0$ for liquids of composition J and also for those of composition J_1 .

Zone refining is normally used on material already of high purity, and the theory therefore is concerned with points on the phase diagrams near the right- or left-hand axis. Thus in figures 2 and 5, J will be considered to represent solutions containing impurity B in component A, while J_1 will represent solutions containing a small amount of A in B. From these figures, and from a study of other types of system, the important generalization emerges that k_i is less than unity when the impurity depresses the melting point of the main component, and more than unity when it raises it. If the presence of impurity has no effect on the melting point of the main component, then k_i is unity and no separation of the components is possible by zone refining. At the eutectic point C (figure 2) k_i is unity: the eutectic freezes without change of composition.

In practice, the solid and the liquid never reach equilibrium; it is the 'effective distribution coefficient' (k) that is relevant: this is the actual ratio of the concentration of impurity in the solid that has just been deposited during a zone-refining experiment to its concentration in the liquid. It will usually lie between k_i and unity and will, of course, approach k_i as the rate of the zone

movement is decreased. The substances to be refined often contain several impurities, but when only small traces of these are present, little interaction occurs among their molecules. Hence it is generally possible to consider effective distribution coefficients separately for each impurity.

Theory shows that while distillation can never yield a 100 per cent pure product, zone refining can give such a product if the mixture has a phase diagram of the type shown in figure 2. Zone refining is usually more effective than distillation for materials that are already reasonably pure, say 99 per cent: if the composition of the starting material is near the eutectic mixture, however, distillation may be more useful. Distillation has the advantage that it can treat tons of material in a continuous process, while present techniques in zone refining can deal with only a few pounds at a time. Other techniques, such as liquid, gas, or ion-exchange chromatography, cannot produce absolutely pure materials, but can be used on very impure mixtures, and are, of course, very valuable for thermally unstable organic substances, although, in general, it is difficult to handle really large quantities of material by these methods.

THE PROCESS OF PURIFICATION

A substance of the type represented by figure 2 can, in theory, be purified by a single passage of the zone: if the initial composition is as represented by J, pure component A should crystallize from the back of the moving zone. This process should continue until the remaining part of the bar has the eutectic composition. In practice, however, liquid that contains some of the impurity is trapped in the growing crystals. Repetition, however, gives an increased purity that results in larger crystals; less impurity is trapped, and the purification becomes increasingly rapid. Figure 6 shows the distribution of impurity obtained after the passage of 1, 10, 20, and an infinite number of zones through an initially uniform rod of relative impurity concentration 1.0, where k is a constant with a value between 0 and 1. The figure shows that no part of the bar can be freed completely from impurity when k has such a value. Moreover, theory shows that the nearer k is to unity, the greater is the ultimate concentration of impurity in the first part of the bar and the greater is the number of passes required to approach this ultimate impurity distribution.

It is possible by zone refining to separate virtually pure specimens of each of the components

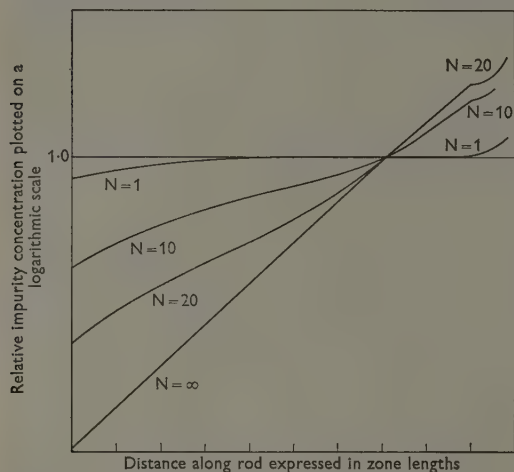


FIGURE 6—Relative impurity concentration after various numbers of passes along a bar when k is less than 1.

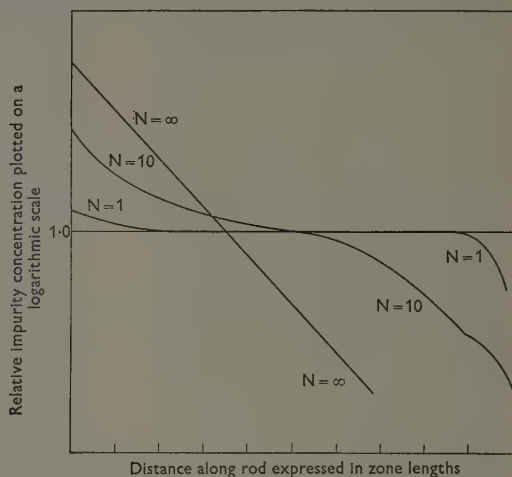


FIGURE 7—Relative impurity concentration after various numbers of passes along a bar when k is greater than 1.

of a mixture of the type represented by figure 5; the bar will finally have essentially pure component A at one end and pure component B at the other. For substances represented by the point J_1 , that is where k is greater than 1, a very large number of passes will be necessary, as the impurity A is moving in a direction opposite to that of the zone, and no molecule of it can move more than one zone length during a single zone pass. Figure 7 shows the distribution of impurity that might be obtained after different numbers (N) of passes for such a system. A material containing some impurities for which k is greater than 1 and others for which it is less, may result in a bar in which the middle part is the purest.

PRACTICAL CONSIDERATIONS

Under given conditions, maximum separation would be obtained with an infinite number of zone passes, but from a practical point of view it is obviously important to know the smallest number that will achieve an adequate separation. The use of a narrow zone will give a high degree of purity; a wide zone will produce more rapid results. In practice, therefore, a wide zone is often used in the early stages, which are followed by the use of a zone whose length is, say, one-tenth that of the bar. Calculations [2] show that, if k is between 0.1 and 0.5, 20 passes will produce almost the maximum purification possible by this method; if it is very near to 1, hundreds of passes may be necessary.

The speed of zone movement is limited by the

fact that too rapid a movement will trap impurities in the crystallizing substance. A speed sufficiently slow for the establishment of equilibrium would, however, normally be too slow for general use. It is found that greater speeds—about 15 cm/h—can be used for metals than for organic compounds, where speeds of 2.5–4.0 cm/h are more usual. The purification of organic substances of high molecular weight may need even lower speeds. The process can sometimes be speeded by moving an arrangement of heating units and cooling units along the bar, so as to achieve simultaneously the effect of a number of zone passages.

The liquid zone must be homogeneous to achieve the maximum possible separation, and, although diffusion may bring about sufficient mixing, additional methods of stirring may be required. Correct design of apparatus will often favour mixing by convection, and if it is possible to arrange for the heater to travel down a vertical tube, vigorous convection currents can usually be set up by making the bottom of the zone hotter than the top. The use of a vertical tube has the additional advantage that an insoluble impurity may fall to the bottom (see figure 3). However, it is important to allow for the physical results of melting; thus, if the solid expands on melting, the zone must be started at the top of the tube to avoid breaking the apparatus.

APPARATUS

Radiant heating is widely used. Temperatures up to 3500°C can be achieved by concentrating

solar energy, and temperatures up to 2000°C can be reached by using the radiant energy from electric heaters. Figure 3 shows a completely automatic apparatus suitable for treating batches of up to 1 kg of organic compounds [3]. The heater, which consists of a small electric coil backed by a stainless steel reflector, is supported by two cords, and is allowed to drop at a controlled rate. When the heater reaches the bottom of the tube it operates a switch controlling an electric motor and a clutch, which raise the heater to the top of the tube again, when another switch is operated and the heater moves downward again. Apparatus similar to this is now commercially obtainable. Some results achieved by the treatment of a mixture of 0.03 per cent of the blue dye, induline, in naphthalene [4] can be seen in figure 4. The tube on the left shows the original material and the other tubes show the separation obtained after, respectively, four and eight passes.

Radiant heating can be employed for the zone refining of low-melting compounds if the equipment is placed in a refrigerated space. In an alternative arrangement the specimen may be confined in an annular space with a radiant heater in the centre, and the whole apparatus surrounded by cooling liquid contained in a Dewar vessel [5].

Figure 8 shows apparatus suitable for refining samples of organic compounds weighing from 0.1 to 10 g. In this, the energy from the bulb of a projection lamp, L, situated at one focus of an ellipsoidal mirror, MM_1 , is concentrated on the sample at the other focus [6]. The sample is

contained in a small tube, which is moved upwards by an electric clock motor, E. A suitable light filter, F, can be used to protect the sample against the effects of intense light. An apparatus modified so that the zone is produced by the radiant energy from a resistance wire round the tube is commercially available. Samples weighing a few milligrams cannot be treated in enclosed tubes because air bubbles are trapped, but G. Hesse and H. Schildknecht [7] have overcome this difficulty by placing the specimen in a cavity along the side of a glass tube.

The floating-zone technique is widely used for treating materials of high melting point, such as silicon. Figure 9 shows two applications of this technique, designed to avoid contamination of the specimen by the container. The rod of material is clamped at each end; the zone is supported by surface tension, and sometimes by additional forces such as those produced by electromagnetic fields. Figure 9a shows the use of induction heating, and figure 9b depicts an apparatus using electron bombardment to melt the zone [8]. Purification is often assisted by the preferential volatilization of impurity in an apparatus such as that shown in figure 9b. When there is no risk of contamination of the sample by the container, materials of high surface tension are often refined in long, thin, horizontal boats heated either by radiant energy or by gas.

APPLICATIONS

Purification by zone refining is a valuable preliminary to the preparation of single crystals. The

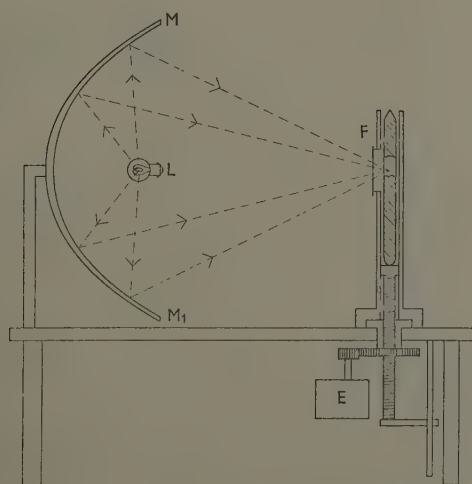


FIGURE 8 — Semi-micro zone-refining apparatus.

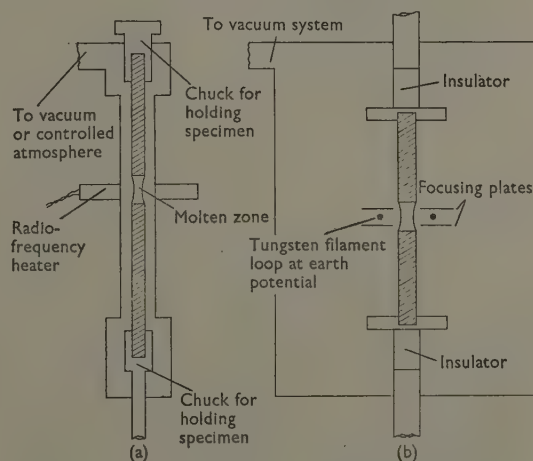


FIGURE 9 — (a) Floating-zone refining using radio-frequency heating. (b) Floating-zone refining using electron-bombardment heating.

realization that many properties of materials, particularly electrical properties, can be modified greatly by small amounts of impurity has led to the study of the zone melting of a very large number of elements. Sometimes an impurity is found to exhibit an effective distribution coefficient too near unity for zone refining to be successful, but even then it may be possible to effect purification by using a suitable compound containing the element. For example, it has been shown [9, 10] that gallium trichloride and indium triiodide can be used for the purification of gallium and indium.

Radioactive tracers have been employed to follow the result of zone refining: the isotopes Na^{22} , Sr^{90} , S^{35} , and P^{32} have been used to show that the ions Na^+ , Sr^{2+} , SO_4^{2-} , and PO_4^{3-} can be removed from potassium nitrate. If a salt itself has too high a melting point, or undergoes decomposition on melting, it is sometimes advantageous to refine a eutectic, such as that formed by the salt with water [11].

Water has been purified by zone refining and it has been reported [12] that over 99.9 per cent

of the sodium chloride can be removed from a solution containing 20 g per litre by a single pass. Even colloids have been removed from solution; for example, it has been observed that colloidal gold tends to concentrate in the last zone frozen [11]. Attempts have been made to separate the components of isotopic mixtures. In such systems k may have a value as near unity as 1.001, yet from water containing 1.96 per cent of deuterium a concentration of 2.01 per cent was obtained at the front of a bar of ice after 40 passes [11].

Many organic compounds have been treated: for example, a high grade of benzoic acid, purified by eight passes, is now offered as a volumetric standard. Dioxane has been purified for spectroscopic use, and anthracene, stilbene, and terphenyl have been zone refined to obtain material for the preparation of single crystals for use in scintillation counters. The possibility of dealing with small samples has facilitated the purification of biological substances—for example, the separation of a wax derived from caterpillars has been achieved [7].

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Radioactive tracers in the atmosphere

N. G. STEWART

The possible consequences of releasing the products of thermonuclear explosions into the atmosphere have aroused much controversy, but for the meteorologist, at least, the radioactive products have provided a completely new means of investigating the circulation of the atmosphere. Although this method is only just beginning to be exploited, some very interesting information has already been obtained, and it is clear that it has great possibilities. This article reviews results obtained in relation to current theories of atmospheric circulation.

The atmosphere is conventionally divided into two main regions: the lower atmosphere, or troposphere, and the stratosphere. The two regions are separated by a boundary called the tropopause, which, by definition, lies where the rate of change of temperature with height alters from its negative value in the troposphere to its zero or positive

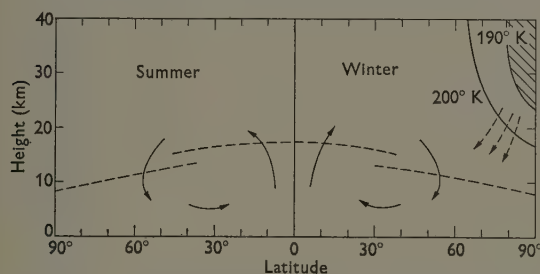


FIGURE 1—Atmospheric circulation model (after Dobson and Brewer), showing the cold pool of air above the winter pole. The dashed lines represent the tropopause and the arrows show the sense of the mean air flow.

value in the stratosphere. The tropopause is not continuous. At the equator it is found at a mean altitude of 17 000 metres, but at latitudes of approximately 30° N and S an abrupt change occurs to about 12 000 metres (figure 1). The discontinuity in the tropopause is often associated with the jet stream, a very strong west-east air current. The stratosphere contains essentially no clouds and is non-turbulent; any gas or fine dust introduced into it spreads slowly, in contrast with the relatively rapid dispersion experienced in the troposphere.

Measurements of the radioactivity of the atmosphere were first carried out more than fifty years ago, and several papers on the radon content of air were published between 1903 and 1908. The subject then lay dormant until about 1951, when the testing of nuclear weapons opened up the prospect of using radioactive clouds for meteorological

research on a global scale. At first the clouds were used to confirm conventional methods of tracking and predicting the movements of air masses in the lower atmosphere, but with the advent of thermonuclear explosions—which sent clouds well into the stratosphere—there arose the interesting possibility of studying the general circulation of the atmosphere.

Other radioactive elements have been used currently in this study, notably the naturally occurring isotopes created in the atmosphere by cosmic rays, and the longer-lived daughter products of radon.

DUST FROM NUCLEAR EXPLOSIONS

In every type of nuclear explosion a considerable fraction of the radioactivity generated is contained in fine dust particles whose rate of fall under gravity is small and which may therefore remain airborne for long periods. The particles consist almost entirely of silica, chalk, or metal oxides, depending on the test conditions, but all types carry small amounts of the 70-odd fission products created in the explosion. The half-lives of the individual fission products vary from fractions of a second to many years, so that the radioactivity of a sample decays in a complex manner, varying with time (t) approximately as $t^{-1.2}$.

Between 1951 and 1954, simple measurements of the radioactivity in the troposphere revealed important differences between the behaviour of clouds from the small, 'nominal', weapons and those from large thermonuclear weapons [1]. It was observed that the dust from a nominal-bomb test remained within the lower atmosphere, from which it was washed out by rain within two to three months. The dust from a thermonuclear test penetrated into the stratosphere and returned very slowly, so that the contamination of the troposphere was sustained for a period of up to several years. The high fission-product content of the stratosphere

some six months after the thermonuclear tests in 1954 is demonstrated in figure 2, which is typical of a series obtained by sampling the air above Britain by filters attached to aircraft. The concentration increases sharply above 12 000 m, the mean height of the tropopause in that area.

After 1954, the frequency of large-scale tests increased. The stratosphere temporarily stored fission products from several different sources, and it became impossible to interpret simple measurements of total radioactivity. Attention was therefore focussed on strontium-90 and caesium-137, which have half-lives of approximately 30 years and are consequently very suitable as tracers for long-period atmospheric movements. In order to study how fission-product dust returns from the stratosphere, world-wide rain-collecting stations were set up, primarily by the United Kingdom and the United States [2]. At each station of the British network, rainwater is collected over quarterly periods and is returned to Harwell, where it is analysed radiochemically for the isotopes Sr^{89} , Sr^{90} , and Cs^{137} . At one station (Milford Haven, Pembrokeshire), monthly samples are also collected. The main results obtained have been based on the analyses for 28-year Sr^{90} and the shorter-lived Sr^{89} , which has a half-life of 50 days. The ratio of Sr^{89} to Sr^{90} in a sample can be used as a measure of the effective age of the fission products: the ratio has a value of about 180 : 1 immediately after an explosion; 50 days later the ratio will be 90 : 1; and so on. Frequently one can use the ratio to determine the relative amounts of new and old fission products in a mixed sample.

The specific Sr^{90} -content, and the $\text{Sr}^{89} : \text{Sr}^{90}$ ratio, of Milford Haven rainwater are shown in figure 3 [3], in which the dates and latitudes of the major thermonuclear tests are indicated [4]. The graph reveals a marked seasonal variation in the specific activity of the rainwater, with peaks in the late spring and troughs in the late autumn of each year. The $\text{Sr}^{89} : \text{Sr}^{90}$ ratio tends to be low in the vicinity of the Sr^{90} peaks, indicating that the bulk of the Sr^{90} is of fairly old origin and has certainly come from the stratosphere. The peaks in 1955 and 1956 are particularly interesting, because the ratio analysis proves that they both derive primarily from the Pacific explosions in the spring of 1954. These results strongly suggest that the dust stored in the stratosphere is returned to earth periodically, and not at a uniform rate. On the average, the specific Sr^{90} -content of rainwater at the six sampling stations

in the United Kingdom has been unaffected by differences of up to 8 : 1 in annual rainfall rates, suggesting that rainwater activity is proportional to air activity and thus can probably be used anywhere as a measure of the latter. This deduction is supported by the observation that in 1955 and 1956 the Cs^{137} content of tropospheric air above the United Kingdom followed the same cyclic variation as the Sr^{90} in rain [5].

For the world network, the Sr^{90} -content of rainwater has been averaged over the whole period of sampling at each station and is plotted against latitude in figure 4. Since a fairly smooth curve can be drawn through the points, despite large differences in the longitudes of the sampling stations, it is reasonable to suppose that the mean Sr^{90} -content of rainwater is in general a function of latitude only. The high value at 70°N was obtained at a station in northern Norway, which may be influenced by its proximity to Russian testing grounds. The most striking feature of the

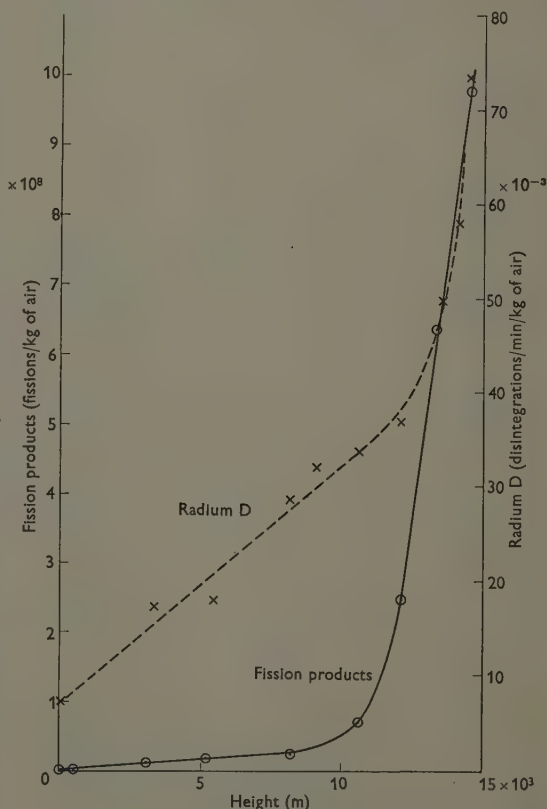


FIGURE 2—Vertical distribution of fission products and radium D in the atmosphere.

curve is that little of the Sr^{90} coming from the stratosphere is being deposited in equatorial latitudes, despite the fact that many of the test explosions took place at latitude 11°N . A similar geographical distribution has been observed by L. B. Lockhart in the concentration of gross radioactivity in ground-level air along the 80th meridian (west) in May and August 1959; the most recent test explosion had then taken place in October 1958 [6]. A final and convincing piece of evidence relating to this non-uniformity of stratospheric fall-out has been reported by L. Machta [7]. In the American test explosions in the Pacific in the summer of 1958, a completely new and unambiguous tracer, tungsten-185, was created in readily detectable amounts, and the distribution curve of this isotope in rainwater was very similar to that shown in figure 4.

Summarizing, the observations imply that Sr^{90} is returned from the stratosphere to the troposphere in a periodic manner and that the bulk of the material is transferred in middle and higher latitudes. These two features must be consequences of the manner in which air is exchanged between the two regions of the atmosphere, and it is interesting to note that they are consistent with the model for the general circulation of the atmosphere proposed by G. M. B. Dobson [8] and A. W. Brewer [9] on the basis of ozone and water-vapour measurements. The water-vapour content of the stratosphere is very low, implying that any air transported upwards from the troposphere must have had its moisture content removed on the way. Brewer has suggested that this upward transfer can occur only near the equator, as indicated by the upward-pointing arrows in figure 1, and that the moisture will be condensed and removed as it travels through the very cold belt of air which is known to exist in a localized band at the equatorial tropopause. Dobson has studied the actual form of the water vapour gradient in the atmosphere and has found it difficult to explain except as the result of the slow sinking of dry air from the stratosphere in the middle latitudes, as indicated in figure 1. These deductions seem to be confirmed by the latitude distribution of Sr^{90} in rainwater. The low values of the concentration in equatorial rain show that Sr^{90} is certainly not descending near the equator, while the high values in the middle latitudes support Dobson's theory of the main region of downward transport.

The seasonal variation of the Sr^{90} -content is remarkably similar to the seasonal variation of

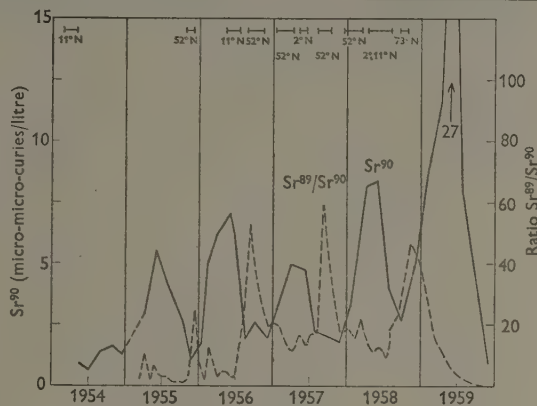


FIGURE 3— Sr^{90} and Sr^{89} concentrations in rainwater at Milford Haven, 1954–59. The symbols at the top indicate the dates and positions of major thermonuclear tests.

total ozone in the atmosphere, which has been observed by many workers. Ozone has a complex history in the atmosphere. There is little doubt that it is created photochemically in the upper atmosphere and that the maximum production rate occurs somewhat above 30 km. At these heights the ozone is relatively unstable in the presence of sunlight and its mean life is relatively short; a state of photochemical equilibrium exists. At lower levels in the stratosphere the ozone is shielded from the effects of sunlight by the ozone above it, and it is consequently much more stable. Thus if a mass of air with a high ozone content sinks from, say, 25 km into the lower stratosphere, it enters a region where its mean life is longer, but since the deficit at 25 km is made up fairly quickly by the creation of fresh ozone, the total amount of ozone in the atmosphere increases.

Dobson postulates that the observed seasonal increase in total ozone in the atmosphere is the result of the sinking of the cold pool of air which forms over the winter pole when it lies in shadow (figure 1). This subsidence brings ozone-rich air into the lower stratosphere in early spring. It is reasonable to postulate that it would also bring Sr^{90} -rich air into the lower stratosphere, since it has already been shown that high concentrations of fission products exist in the stratosphere above 14 km (figure 2). The fresh supply of Sr^{90} in the lower stratosphere would be gradually transferred to the troposphere, introducing a seasonal component into the variation of the concentration of Sr^{90} in tropospheric air and in rain. For reasons of continuity, the subsidence of the cold pool of air would be expected to initiate a meridional flow in

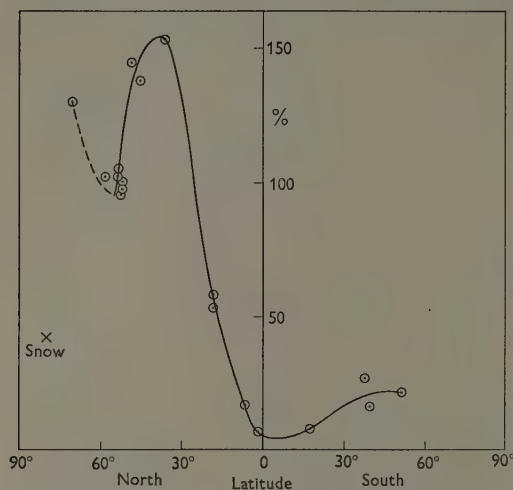


FIGURE 4 - Average Sr^{90} -content of rainwater at various latitudes, 1956-59.

the stratosphere which would encourage a poleward drift of fission products from lower latitudes in the stratosphere. This flow would tend to limit the fission products from a test explosion to the hemisphere in which the explosion took place and, since all thermonuclear explosions to date have been held in the northern hemisphere, would qualitatively account for the fact that more Sr^{90} is deposited in the northern than in the southern hemisphere (figure 4).

E. A. Martell has presented evidence to show that the stratospheric clouds from Russian tests held in more northerly latitudes are deposited much more quickly than those from Pacific tests [4]. This could account in part for the large Sr^{90} peak in 1959 following the explosions in Russia in the autumn of 1958, although J. Ambrosen has shown that about 50 per cent of this peak must be attributed to older debris [10]. Martell's conclusion is not inconsistent with the Dobson-Brewer model, since the clouds from explosions in the north enter the stratosphere nearer to the region of sinking stratospheric air and to the region of entry into the troposphere. The result would be all the more expected if a significant portion of the dust from the Russian explosion did not rise above the lower layers of the stratosphere. Martell, however, also attributes much of the observed seasonal peaks to immediately preceding Russian tests rather than to meteorological causes. This view cannot reasonably account for the 1955 and 1956 peaks, which can be associated

in the main only with the 1954 explosions. Since no major tests have been held since 1958, Martell's interpretation cannot be applied to any peaks which may appear in 1960, or in later years if the suspension in testing continues, and further results are awaited with interest.

ISOTOPES PRODUCED BY COSMIC RAYS

Several radioactive isotopes are produced by the nuclear disruption of nitrogen, oxygen, and argon by high-energy cosmic rays, and B. Peters has suggested that some of these could supplement fission products as tools for studying air circulation [11]. Two isotopes with suitable half-lives are 53-day Be^7 and 14-day P^{32} , which are created primarily, but not exclusively, in the upper layers of the atmosphere. The production rate is essentially constant, and the isotopes are ultimately removed from the atmosphere by radioactive decay or by precipitation.

Peters shows that the deposition rate of Be^7 is nearly as high in tropical regions as it is in Chicago, so that the deposition pattern has not the shape characteristic of dust that has come primarily from the stratosphere (figure 4). He concludes that most of the Be^7 created in the stratosphere decays before it can be transported into the lower atmosphere, and that the Be^7 deposited in rain is produced primarily in the troposphere. This is consistent with the fact that the flux of the cosmic rays which generate Be^7 (and P^{32}) in the troposphere does not vary appreciably with latitude.

Because of their long average residence-time, the isotopes formed in the stratosphere can build up to a state of radioactive equilibrium, and the calculated value of the ratio of Be^7 to P^{32} is 400. The mean residence period in the troposphere, based on fission-product data, is about 30 days, and in this time the ratio can attain a value of only about 140. This makes it possible to detect the presence in the troposphere of air that has come from the stratosphere and suggests that cosmic-ray radioactivity may be useful in the study of large-scale air circulation. For example, the ratio in tropical rains in India was measured [12]: a mean value of 150 was obtained from 21 samples, with one extreme value of 290. If an appreciable amount of air from the stratosphere had entered any of the samples, the $Be^7 : P^{32}$ ratio would have been much higher. This result is consistent with the low Sr^{90} -concentrations found in equatorial rain and in this sense supports the Dobson-Brewer circulation model.

Other important radioactive isotopes produced in the atmosphere by cosmic rays are C^{14} and tritium, which are also produced and released into the stratosphere in the testing of large nuclear weapons. Experiments have been carried out [13] in which the excess of C^{14} and tritium above that naturally present in the stratosphere was measured by balloon-sampling at heights up to 30 000 metres. The results showed a clear poleward drift of C^{14} which had been injected high into the stratosphere some 15 months earlier at a latitude of 11° N. A drift of this nature is implied in the Dobson-Brewer circulation model and by the non-uniformity of the deposition of Sr^{90} .

RADON-DECAY PRODUCTS

A feature common to all the tracers described so far is that their effective source lies in the stratosphere. Consequently they can be used directly to study the mechanism of transport of air from stratosphere to troposphere, but not the complementary transport in the opposite direction. W. M. Burton and N. G. Stewart have recently proposed that the long-lived daughter-products of natural radon would be suitable for this purpose [14]. Being a gas, it can escape from the earth's crust into the atmosphere, where it disintegrates to form a chain of solid daughter-products. Radium D (half-life 19.4 y) and radium F (half-life 138.4d) are suitable for atmospheric-circulation studies. The atmospheric distribution of radium D above the United Kingdom, as determined by air filtration and radiochemical analysis of the product, is shown—together with the fission-product distribution curve—in figure 2, in which each point represents the average of a number of samples. The concentration of radium D per unit mass of air increases slowly with height in the

troposphere, but the gradient increases sharply in the stratosphere and is just as steep as that of the descending fission products. This rather surprising result suggests that some RaD is descending from the stratosphere in middle latitudes to supplement the larger concentrations created directly in the troposphere. The source of this descending RaD must be radon and its daughter-products, carried by tropospheric air which rises into the stratosphere in some other region. The obvious deduction is that this takes place near the equator, as suggested by Dobson and Brewer.

The ratio of the activity of radium F to that of radium D, which is zero when the radium D is freshly formed and approaches unity in about 500 days, can be used as a measure of the length of time the tracer atoms spend in the atmosphere. At ground-level and in rainwater the mean value is 0.10, which implies that the mean life of an atom in the troposphere before it is deposited by rain is 29 days. In the lower stratosphere above the United Kingdom the value of the ratio is 0.65, corresponding to a residence period of 212 days. The difference between these two residence times—183 days, or about 6 months—can be taken as the length of time the ascending tropical air spends in the stratosphere before returning to the troposphere in middle latitudes.

CONCLUSION

The results from the experiments described have been interpreted in terms of the Dobson-Brewer model of atmospheric circulation, which they appear to fit reasonably well. Not all meteorologists accept this picture—there are dynamical difficulties associated with it—and it may be that the data can be fitted to some more acceptable theory in due course.

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Bower-birds

A. J. MARSHALL

The bower-birds have developed to a remarkable degree the not uncommon avian tendency to build arenas and to display at them. Bower-birds are not easily studied, and it is only comparatively recently that a scientific explanation of their bizarre behaviour has been attempted. The author refutes the popular belief that the display is either indiscriminate or satisfies some conscious aestheticism: he regards bower building as a consequence of displaced nesting instinct. The photographs illustrating this article were taken by Mr Norman Chaffer.

About the turn of the last century, in the wild Ord River country of Western Australia, a Mr Edward Delaney missed his spectacles. Mr. Delaney has become posthumously celebrated because the glasses were stolen from his veranda by a Great Grey Bower-bird (*Chlamydera nuchalis*) and carried off for the decoration of its bower. On display-grounds of the same species have been found bright specimens of gold embedded in quartz and, sometimes, fragments of precious opal.

A. H. Chisholm has given an account of a Spotted Bower-bird (*C. maculata*) that would appear incredible if the scavenging tendencies of this small, lilac-crested bird were not so well attested. A glass eye that the owner used to keep overnight by his bedside was discovered among the agglomeration of display objects on a neighbouring bower.

In some Australian country districts, aborigines search the bowers of Spotted Bower-birds after every race-meeting in the hope of finding coins lost by racegoers: when sovereigns were in circulation, the search was often very profitable. The Spotted Bower-bird is known to go through open windows to take jewellery from dressing tables. The ornithologist A. J. North reported that scissors, knives, spoons, forks, and coins were pilfered. S. W. Jackson reported that in his camps it was necessary to keep anything bright in a box. He had to retrieve some of his tableware and a pair of entomological forceps from a nearby bower. Another reliable witness has written of the disappearance of the ignition key from his motor car.

The closer a bower is built to human habitation the more startling its decorations tend to be. Thus, on the display grounds of Satin Bower-birds on the borders of Sydney such objects have been found as: blue domestic flowers—petunia, hyacinth, cineraria, delphinium, and jacaranda; a fragment of a blue piano castor; a child's blue mug, a blue-bordered handkerchief; and bus tickets. These treasures may be mixed up with

the moulted blue feathers of parrots, the lemon-yellow flowers of the *Billadiera* creeper, grey fragments of the sloughed skin of snakes, and brown shells of native snails.

Little wonder, then, that bower-birds were given a reputation for the indiscriminate accumulation of picturesque rubbish. Soon people were applying the term 'bower-bird' to children who collected colourful junk. But, in fact, bower-birds do not decorate incongruously, nor do they display indiscriminately. There is a pattern in the rubbish for those who will seek it.

Bower-birds are very much a part of the folklore of Australia. While most of the stories told about them are true, the usual interpretation of them is not. The naturalist John Gould named the family in Victorian times, and shrewdly judged that the bowers or 'runs' were essentially places where the male courted the female. Later, as further details of the complicated displays became known, there arose a school who held that the sexual motive is subsidiary, or even non-existent, and that bower-birds are highly intelligent animals that build bowers, and display at them, in a kind of conscious aestheticism. This is nonsense. It has taken about twenty years to elevate our understanding of this bizarre group of birds from folk-lore to something approaching science [1], and even now next to nothing is known about some of the Australian, and all the New Guinea, members of the family.

Bower-birds are passerine (perching) birds related to birds-of-paradise and crows. They are confined to Australia and New Guinea, but within these countries they have radiated widely and inhabit rain-forest, savannah, grassland, and semi-desert. Some are strikingly beautiful, the males in particular being adorned with erectile crests, or with body plumage that creates a shimmering beauty by means of interference effects. In only one species—the Brown Gardener



FIGURE 1 — Maypole bower of the Queensland Gardener. These structures are sometimes about nine feet high.

of New Guinea—are both sexes quite dull in appearance. This bird, incidentally, builds a circular waterproof hut of epiphytes, and outside it plants a garden of moss on which it places brilliant flowers and piles of freshly gathered fruit and fungi. In a very dense rain-forest, the nineteenth-century Italian naturalist Beccari was startled to see a 'conical hut or bower close to a small (artificial) meadow enamelled with flowers'. It would seem, perhaps, that the Brown Gardener compensates for its lack of beautiful display plumage with its almost unsurpassed accumulation of display paraphernalia. This view has in fact been put forward, but ignores the fact that the male Satin Bower-bird, himself of scintillating physical beauty of plumage, beak, and eye, makes an equally striking and colourful display on the floor of the Australian rain-forest.

I have divided bower-birds into three groups, the closely related cat-birds forming another. Those in the first group build 'avenue' bowers (figures 4-8, 12, and 13) and belong to the genera *Ptilonorhynchus*, *Chlamydera*, and *Sericulus*. The birds of the second group build 'maypole' bowers (figure 1) and belong to the genera *Prionodura* and *Amblyornis*. The third group

comprises the single New Guinea genus *Archboldia*; this bird builds a simple 'platform' bower. Of the three species of cat-bird (genera *Ailurædus* and *Scenopates*), only one makes a display. This species, the Stagemaker or Toothbilled Cat-bird (*S. dentirotis*), is confined to a single species-refuge—a couple of isolated patches of jungle in North Queensland. The other two cat-birds (*Ailurædus*) are green birds that inhabit the leafy canopy. The Toothbill, however, has become brownish; it now spends much of its time on or near the dark jungle floor. It clears a bare stage on the ground and laboriously saws through leaf-petioles with the 'toothed' beak it has developed. It carries these large leaves to its display stage, where it places them with their pale undersides upward; the stage properties thus achieve a more striking contrast with the dark earth. When I turned them over, the bird rearranged them once more to its traditional liking. From a special singing perch above this display it sends a stream of melody through the dim forest; thus it advertises its presence, and ownership of the immediate territory, to every potential mate and rival male within hundreds of yards.

The bower-birds have established independently essentially the same behavioural complex,



FIGURE 2—The *Satin Bower-bird* flourishes on the fringes of the rain-forest.



FIGURE 3—Some display-objects of the *Satin Bower-bird*.



FIGURE 4—The male brings a leaf to his avenue bower. His display will attract a female. (This and figures 5–8 show the *Satin Bower-bird*.)



FIGURE 5—The adult male plasters his bower with a mixture of charcoal and saliva. Some use fruit pulp.



FIGURE 6—The female spends more and more time silently watching the male display and waiting in or beside the bower.



FIGURE 7 — As the sexual season progresses, the male display becomes more violent, and he noisily gyrates about the display ground.



FIGURE 8 — At last the female adopts a special crouching posture that transfers the physical attention of the male from the coloured display-objects.



FIGURE 9 — The Queensland Gardener brings lichens and orchids to his bower (see also figure 1).



FIGURE 10 — Like that of other bower-birds, the plumage of the male Queensland Gardener shimmers as a result of interference effects.



FIGURE 11 — Berries collected for bower-decorations by the golden Queensland Gardener.



FIGURE 12—*The Spotted Bower-bird. It collects mostly bones, but will take also anything bright.*



FIGURE 13 (above)—*The Great Grey Bower-bird is a close relative of the Spotted. It, too, is mottled and unobtrusive in colour pattern.*



FIGURE 14 (right)—*If a bower of the Great Grey Bower-bird is built near human habitation the most surprising articles may be found on its display-ground. It does not hesitate to enter tents or even houses if it sees something that it wants.*

but with many additional (and sometimes grotesque) specializations. The Satin Bower-bird (figures 4-8) is the best known of them. It flourishes on the fringe of the rain-forests that skirt the eastern coast of Australia (figure 2). Towards the end of winter, each glistening blue-black male returns to its bower territory and builds a double-walled bower of thin twigs. The bower points to within a few degrees of North and South. At the same time the sex organs have begun their seasonal enlargement, with the accompanying production of sex hormone. The male brings display-objects of five different colours to what becomes a display-ground in front of the bower. With these objects—which may be as various as a bluebell and a beer-bottle top—the male displays noisily and energetically and soon attracts a female to the arena. Early in the season she tends to stray, and the male then employs a special call to bring her back. With the heightening of the sexual season the bond between the pair becomes more stable, and the female spends more and more time silently watching and waiting in or beside the bower. Other pairs are doing much the same thing nearby, and if a male leaves his bower unguarded, a neighbouring rival will almost certainly fly down, creep stealthily through the undergrowth, and vigorously set to work to wreck it. When leaving, he snatches up and carries away a beakful of the other's laboriously gathered decorations. If surprised at the bower, the interloper always flees from the screeching, swooping, owner.

Meanwhile many, but not all, adult males begin to plaster their bowers with a thick, black, tacky material made from a mixture of charcoal compounded with saliva. With a bark wad held between the tips of the beak, the plaster is forced between the mandibles and so transferred to the inside sticks of the bower (figure 5). Here it looks like black paint, but it dries to a powder and ultimately wears off or is washed off by rain. The plastering operation is repeated often. Some Satin Bower-birds plaster their bowers with fruit-pulp, as do Regent Bower-birds (*Sericulus chrysocephalus*). Some members of the genus *Chlamydera* paint their bowers with dry grass mixed with saliva.

The display may continue for four months without any contact between male and female. The female is waiting for a stimulus beyond the immediate vicinity of the bower: her gonads grow only slowly. The male displays more energetically in her presence, and early develops bunched spermatozoa. Nevertheless, his whole attention, except when the female tends to stray, is still

directed to decoration-gathering, display, and the constant refurbishing of the bower itself.

As time goes on, his display becomes more vigorous and he noisily gyrates about the display ground, tossing the decorations about violently (figure 7). If we examine the colours of these decorations we see that they match closely those of the bodies of rival males (figure 3). The blue, the male eyes and plumage; the peculiar yellow-green, the beak-tip; the yellow, grey, and brown, the colours of younger males not yet into adult plumage. The sexual display, then, is also displaced aggression. It seems probable, too, that the bower-plastering is basically courtship feeding, displaced and directed towards the focal point of the male's attention, the bower.

At last, when the forest becomes full of the summer harvest of flying insects on which she will feed her young, the female makes a positive response. She now crouches in or near the bower in an attitude never seen at any other time of the year. This transfers the physical attention of the male from the decorations to the female (figure 8) [2, 3]. Copulation occurs, the bower sometimes being partly demolished during the act. The violence that has permeated the bower display for so long is sometimes so sustained that, immediately after copulation, the male has been seen—and photographed—attacking the female ferociously and driving her from the bower [3].

After insemination, the female lays from one to three eggs in a nest built in a tree which may be some hundreds of yards from the bower. The male continues his display and apparently takes no part in nest-building, incubation, or the care of the young. Only when the young birds fly does the male desert his bower. Various family parties then join up in communal feeding flocks that range through the forest in search of wild—and sometimes cultivated—fruit. Throughout the late autumn and winter, however, the male will occasionally return to his bower territory, gather a few decorations, rebuild, and display briefly, before rejoining the flock.

Of the avenue-builders, the Spotted and Great Grey Bower-birds (figures 12, 13) are best known. These, as would be surmised from their paler plumage pattern, inhabit the drier parts of the continent. In each species a small erectile nuchal crest relieves the relatively quiet plumage. The basic colour of this crest is orange, but the remarkable cellular structure of the distal barbs causes it to appear rose-lilac in the sunshine, when it sometimes glistens like silver [1]. It is probably

no coincidence that both these bower-birds accumulate chiefly shining or otherwise reflecting ornaments at their display grounds, although both also gather ornaments of other kinds (figure 14). The bower display of the Spotted Bower-bird is the better known of the two: in essence it is similar to that of the Satin Bird. One of the few people to have seen the culmination of the bower display described how the male 'aggressively attacked the bones and odd sticks, or, leaping high, attacked a tree-trunk' after copulation [4].

Little is known in detail of the other principal group of bower-birds, the maypole builders. Each species first weaves a cone of fibrous material around the base of a sapling growing in the rain-forest. The sole Australian representative, the golden Queensland Gardener (*Prionodura newtoniana*), extends this basal cone a considerable distance up the trunk (figure 1); the work of generations of birds has sometimes resulted in structures about nine feet high. These golden males make into hanging gardens by the transference of grey-green lichens, creamy flowers (including sometimes living epiphytic orchids) and berries (figures 9-11). The male displays on a special singing-stick beneath his hanging garden and in trees nearby.

The reason why we know so little about these maypole builders is simple. All except one inhabit New Guinea rain-forests, and there, though the birds are relatively common, zoologists are not. Valuable, if necessarily fragmentary, data concerning the displays of a few of them have nevertheless been brought back [5, 6]. The sole Australian maypole-builder, the Queensland Gardener, also inhabits areas relatively remote from human habitation [7]. Moreover, most people who have visited its rain-forests have been collectors or, more recently, photographers.

Remarkable as they are, the bowers and display paraphernalia of bower-birds are no more than an extension of the territorial and display impulses to be found in other birds. Avian display—visual and auditory—is usually associated with conflict and the establishment of territorial domination, pair formation, and seasonal gonad development; final synchronization of the sexual processes of the pair occurs when the environment changes seasonally to a state appropriate for successful reproduction.

Only then will the female accept the male. All kinds of widely unrelated birds—for example waders, grouse, manakins, and lyre-birds—make simple display-grounds and posture on them during their sexual season. These arenas are examples of convergent evolution.

In bower-birds a simple display came first. The ontogeny, so to speak, of the Satin Bower-bird's display can be seen in the increasing elaboration of its ritual as the individual gains in maturity and experience. By scattering a few fragments of blue glass under a wild fig tree on which the young were feeding, I could stimulate them to fly down, to snatch up the glass, and to display even without a bower. Later the young green males would build a simple platform of a few twigs and display there with accumulated coloured objects: generally these would be stolen by neighbouring adult blue males and carried off to their bowers. As the young green birds grow older they make low-walled avenue bowers, but before they themselves change at the age of five or six years to a mature blue-black they are capable of building a bower as elaborate as that of their elders.

I see the bower as a result of a displaced nesting-drive. The male, which takes no part in nest building, erects a structure on his display arena. The bower-birds have developed this display tendency—known in various other species—to an extraordinary degree, and as we have seen, some species select coloured objects in the image of male rivals and use them violently in a noisy display that attracts the female and deters interlopers. Strong—one could say ferocious—intra-specific competition has been a powerful factor in the evolution of bower-bird display. Much has been written about the supposed intelligence of bower-birds, but there is evidence that they are no more intelligent than other highly developed passerine species. Much, too, has been written of their alleged conscious artistry. One would not, of course, suggest that they do not enjoy collecting display paraphernalia and using them at the arena, but their choice is essentially mechanical and unvarying. A species that uses greenish-yellow, for example, will never select green. None, as far as we know, ever varies its colour scheme as would, say, a woman arranging flowers.

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Early history of comparative anatomy

W. E. SWINTON

Comparative anatomy is now so firmly established that it is easy to forget that it once excited fierce controversy and that its basic principles were laid down relatively recently. This article reviews the early history of the subject, with special reference to the contributions of Lamarck and Cuvier. An interesting relationship is established between comparative anatomy and the industrial revolution, in that the extensive excavations associated with the latter in civil engineering projects provided much of the essential fossil material.

The early history of comparative anatomy shows it largely as a study of the anatomy of animals as compared with that of man. There were writers, Leonardo da Vinci and Francis Bacon among them, who recommended unprejudiced comparison, but the approach was that of regarding man as the perfect specimen, the basis of all anatomical standards. Even John Hunter, often regarded as the father of modern comparative anatomy, could state in 1780 that when he compared the human being with the quadruped, he was reminded of two machines—the one made by an artist, the other an imitation made by a novice.

One reason for this emphasis was that the early study of anatomy was largely a part of medicine: the early human-anatomists had little material for dissection, and lecturers described human structures to their students while a prosector demonstrated the structures, often irrelevant, of lower mammals. The culmination of comparative anatomy in this sense was the vast collection made by John Hunter in the last half of the eighteenth century, which was based almost entirely on the practice of medicine and surgery. Hunter's investigations extended to over five hundred species.

Nevertheless, by the beginning of the nineteenth century the foundations had been laid for the structure of modern palaeontology and comparative anatomy that was to be built during the next fifty years: Linnaeus had laid down a satisfactory basis for the naming and classification of animals, and the great extension of mining, quarrying, and civil engineering that was a feature of the industrial revolution had exposed a wealth of new limestones, sands, and other fossil-bearing rocks.

It is difficult to establish who first realized that every stratum had its characteristic pattern of fossils and that the one was a guide to the other. In England, the first was J. Michell, a physicist well known as the inventor of the torsion balance. In 1760 he published a paper on 'The course and

phenomena of earthquakes', in which he clearly defined the nature of strata and stated that it was impossible to unravel the geological irregularities of England and France without a general knowledge of the fossils in the rocks. In France, Buffon had pointed out that fossils indicated the succession of time, and in 1780 the Abbé J. L. Giraud-Soulavie published the first volume of his *Histoire naturelle de la France méridionale*; his studies of limestone fossils had led him to a realization of the general relationships between these and the limestones in which they occurred. The first geological map of France was published in the same year; it was prepared by J. E. Guettard and A. L. Lavoisier—although primarily a chemist, Lavoisier undertook a number of other duties in the service of the French Government.

William Smith, a mineral surveyor and civil engineer, was the first completely to establish the relationship between rocks and their fossils. His work took him to engineering structures and excavations, and an interest in natural history led him to make the most of the geological information he gained. He soon saw the advantages of being able to recognize the limits of strata, and in 1799 he prepared what was probably the first real geological map. His most important work, however, was a more ambitious 'Geological Map of England and Wales,' which he produced in 1815. This formed the basis of twenty-one separate county-maps, and in it he gave a detailed correlation between the strata and the fossils they contained. His maps and collections have survived and are kept in the British Museum (Natural History) in London.

By 1820, then, there was a clear appreciation of the succession of strata and their fossils; the significance of this in the development of palaeontology and comparative anatomy cannot be over-emphasized. Fossils had, of course, long been known—Leonardo was among those who collected

them—but at last they were accepted for what they were; previous writers—Leibniz in his *Protogæa* (1749) was one of them—had maintained that they were records of life, but many people had held them to be ‘figured stones.’ The increasing lists of fossils discovered in the quarries, cuttings, and mines of the industrial revolution were paralleled by the extension of the lists of living plants and animals that resulted from contemporary geographical explorations: it became clear that there were considerable inconsistencies between the records of the rocks and the rosters of the living. Some living species had apparently no history in the rocks; conversely, many fossils were without modern counterparts. There appeared to be tides in the history of living creatures; some of the fossils of one stratum were not carried forward into the next. This posed a problem: were those that passed from one stratum to the next the survivors of some catastrophe?

Belief in catastrophism was at its height in France; on the other hand, descriptive palaeontology and biology were thriving there. Giraud-Soulavie was, as has been mentioned, examining limestone fossils; Buffon was describing living animals in detail; and Louis Daubenton valuably supplemented Buffon’s work. To each of Buffon’s monographs Daubenton added descriptions of the bone structure and comparisons of the structures in different animals and in man—he stressed the need for this type of comparison. Buffon and Daubenton were, in fact, demonstrating both the complexity and uniformity of zoological morphology. Comparative anatomy was also being studied in England, though still mainly for medical purposes.

There could, however, be no proper correlation between geology, fossils, and comparative anatomy without some understanding of the time scale. John Hutton of Edinburgh, in his ‘Theory of the Earth’ (1785), had stated that the natural forces that produced visible geographical changes could, given sufficient time, have produced the changes in the earth to which geology bore witness. An article in ENDEAVOUR [Vol. VI, 109, 1947] has described this early exposition of ‘uniformitarianism’, which was followed by John Playfair’s in 1802; the theory was not firmly established until the publication of Charles Lyell’s ‘Principles of Geology’ (1830–33), effectively the basis of modern geology. These developments were neglected in France, and, indeed, in the rest of Europe, even though Lyell’s work was on a European scale. Progress came from the development of palaeon-

tology and of comparative anatomy; the two giants of this period were the French biologists Lamarck and Cuvier.

Lamarck—Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck—was born in 1744. He abandoned his army career because of ill health and turned to the study of botany; he soon attained a considerable reputation as a botanist. In 1793 the revolutionary National Convention, somewhat surprisingly, appointed him professor of zoology at the *Jardin des Plantes*. Another chair at Paris was filled in 1809 by the appointment of Geoffroy Saint-Hilaire, who had previously been a mineralogist and had accompanied Napoleon to Egypt to collect fossils. Thereafter the botanist lectured on invertebrates and the mineralogist on vertebrates, and each made a great success of his task.

Lamarck settled down to do serious zoological research and became a voluminous writer on his new subject; he deservedly established a sound reputation for himself on the purely systematic side of his work. He was also a speculative thinker and produced theories on the descent of animals and on their variations, adaptations, and classification, which—though overlooked at the time—have since given him the reputation of a forerunner of Darwin and a believer in evolution. He realized that man had introduced many of his own interpretations into the corpus of zoological knowledge, and therefore, while recognizing that animals are individuals with characters that may show or suggest affinities, he considered that much of their classification was wholly artificial.

He was not a believer in catastrophism, and suggested that living animals are the descendants of previously living creatures and not the results of separate creation. Many of them he believed to have become modified, though some of the reasons Lamarck gave for their modification are now regarded as ridiculous. The celebrated theory that the lengthening of the giraffe’s neck is to enable it to eat from trees, and the idea that the development of horns in the male ruminants comes about through increased blood supplies to the head during the mating season, are absurdities that are often thought to detract from the really prophetic suggestions he made about modification and descent. Unfortunately his life was beset with difficulties, and he was often led to advance ideas merely because they countered those of his rival Cuvier, who did nothing to relieve a situation that now we see only as regrettable. Nor did his supporters advance his cause, for many of them

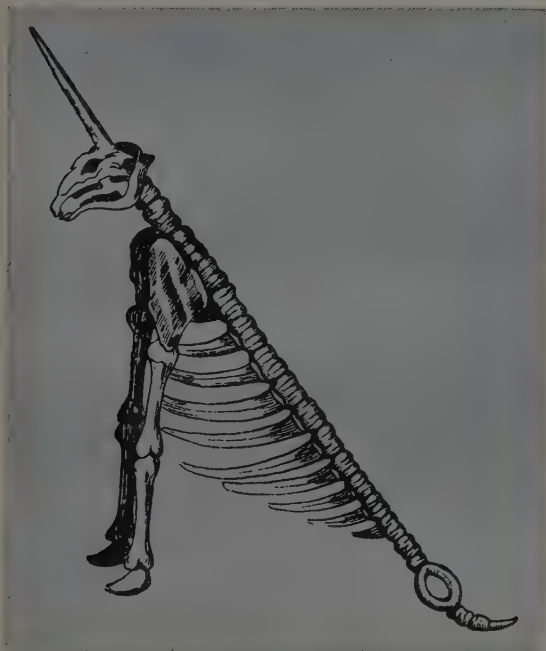


FIGURE 1 - The earliest vertebrate restoration: bones of a mammoth unnaturally arranged to represent a unicorn. Composed by Otto von Guericke in 1663, it was approved and published by Leibniz in 1749.

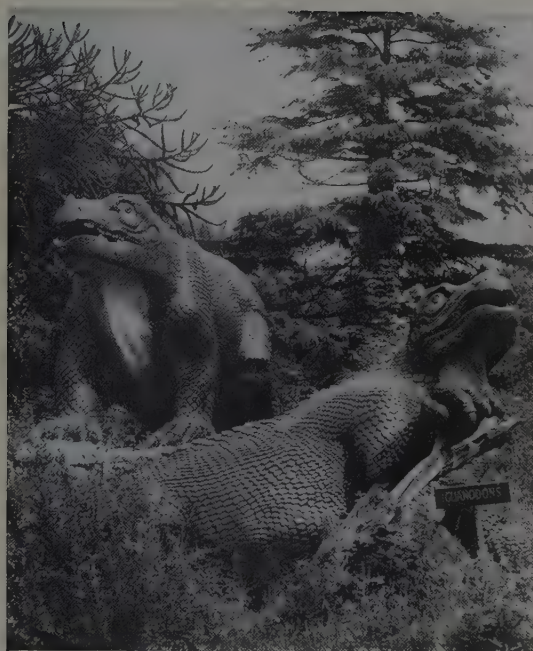


FIGURE 2 - The first three-dimensional reconstruction from a fossil: a model of a dinosaur, an iguanodon, as made by Gideon Mantell. About 30 ft long.

did much harm by the wildness of their evolutionary schemes.

The time was ripe for a unification of biological knowledge; the agent was Georges Léopold Chrétien Frédéric Dagobert, Baron Cuvier.

He was born in 1769, and studied at Stuttgart, where he devoted his time to zoology; he was appointed assistant to the professor of comparative anatomy at the *Muséum d'Histoire Naturelle* in 1795. In 1802 he was appointed titular professor at the *Jardin des Plantes*, and thus became a colleague of Lamarck and, shortly afterwards, of Saint-Hilaire.

Cuvier's predecessors had been medically trained and qualified. They included Petrus Camper, who had published monographs on the elephant and the rhinoceros, and J. F. Blumenbach, who introduced the study of comparative anatomy into Germany. Cuvier himself, with no medical background, could, perhaps, more easily approach the subject in a purely scientific way.

He was interested in the morphology of the groups he studied, and divested the subject of all speculative and unconfirmed material. Thus when, in 1811, he went to Haarlem he was glad to take

the opportunity of examining the famous fossil *Homo diluvii testis* (man a witness of the deluge) which had been described, and generally accepted, as the skeleton of a child drowned in the Flood (figure 6). The identification had been published in 1726 by Johannes Scheuchzer and had caused a considerable sensation. Cuvier's factual methods of examination resulted in his reaching the less sensational but more useful verdict that the skeleton was that of a fossil salamander.

Palaeontology, even more than zoology, was at this time in dire need of an interpreter. Published descriptions and restorations of the first great skeletons had shown ideas that were under the influence of mythology rather than of science (figure 1). Cuvier soon remedied this. The lessons taught by Giraud-Soulavie were not lost on him, and, with the geologist Alexandre Brongniart as assistant, he began to make serious studies, by new methods, of the fossils that could be found so conveniently in the Paris Basin.

These fossils had been studied before, and for Cuvier they offered all the evidence of the catastrophism in which he believed. Nevertheless they were now examined, skeleton by skeleton, piece



FIGURE 3—*Partial skeleton of Palaeotherium, an Eocene mammal from Pantin in Paris (Ossemens fossiles, second edition, 1822). (See also figure 5.)*

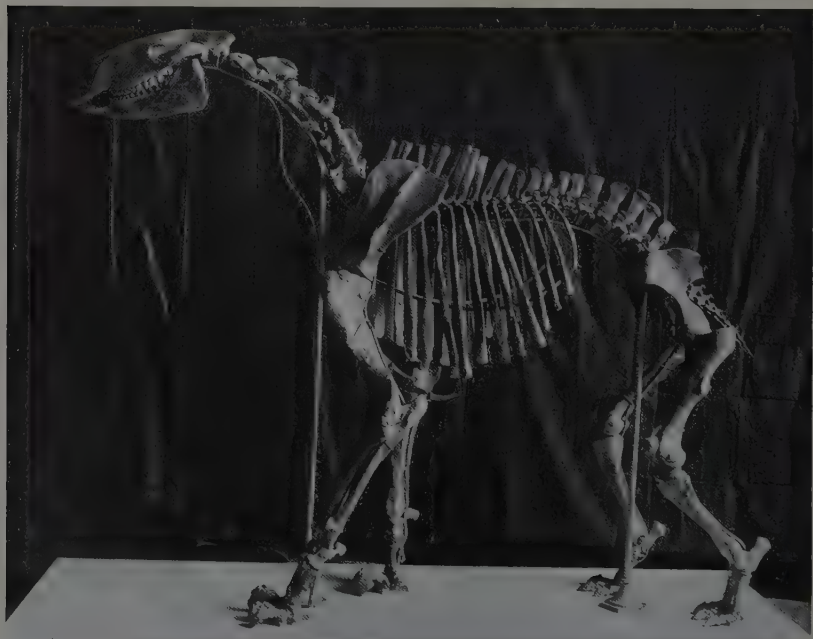


FIGURE 4—Moropus, a *Miocene* herbivore with grinding-teeth and clawed feet. As large as a horse.

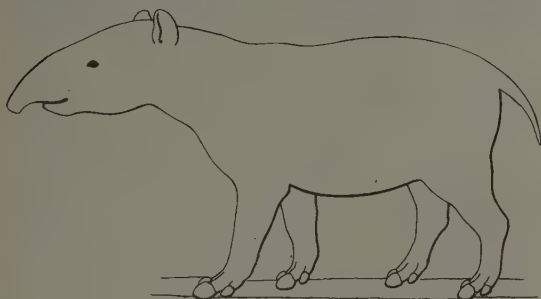


FIGURE 5—Cuvier's restoration of *Palaeotherium*, based on his studies of comparative anatomy. The size of a small rhinoceros.

by piece, and their position in the rocks was carefully noted, together with the relationship of one fossil to another. The beginnings of palaeoecology were thus made. Cuvier found that by comparing his fossils with living mammals he was able to complete partial skeletons on sound osteological grounds (figure 3). Further, he could add in due course the evidence of the fossil animals to reinforce knowledge of the living. Thus he derived vertebrate palaeontology partly from vertebrate zoology, and, conversely, aided classification by applying palaeontology to zoology.

His studies were not limited to bones, for although his approach was essentially empirical, he made every effort to understand the kind of soft tissues that might be expected to be associated with the bones (figure 5). His ultimate intention was to write a vast treatise on comparative anatomy; but this was never achieved, though his classic work, *Recherches sur les ossements fossiles*, is perhaps monument enough and certainly sufficient to establish him as the founder of vertebrate palaeontology. As a zoologist he made possible a fuller understanding of the animals he studied and gave a much-needed amplification to the somewhat narrowly taxonomic studies of Linnaeus, who still had immense authority and whose writings were still examination textbooks. He proved that the zoological series—however much it might be enhanced, almost daily, by fresh geographical discovery—still needed the amplification that fossils gave. At once it became clear that, however fossils might have been produced, there were variations in the record of the continuity of life: forms appeared and disappeared in the records of the rocks, and they might, or might not, have representatives in the living world. This had been seen before, but now the biological implications of extinction began to be realized. A

new problem then arose: had some forms been transformed into others? Lamarck saw life as a continuous and progressive series, but to Cuvier there was only a succession of fixed species, a zoological ladder. This may seem a limitation of the industrious genius of Cuvier, but if so it was perhaps fortunate, since it enabled him to give

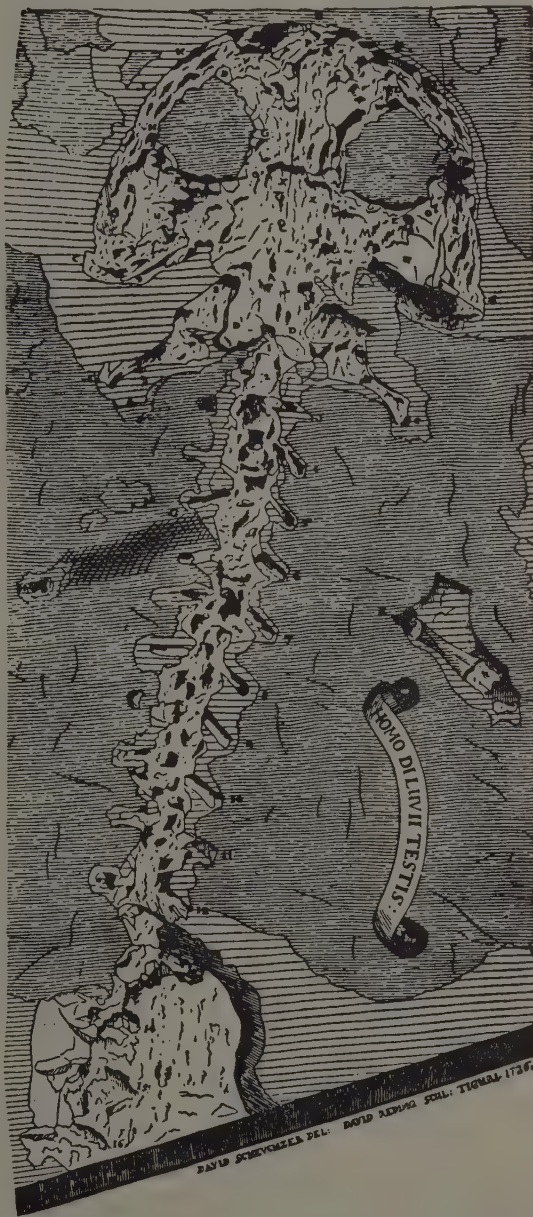


FIGURE 6—Scheuchzer's broadsheet recounting the discovery in 1726 of *Homo diluvii testis*, proved by Cuvier to be a fossil salamander.

meticulous attention to detail and to found the science of vertebrate palaeontology.

Cuvier believed that conformity in all parts of an animal was necessary and that each part was modified in accordance with the other parts. This was the essence of Cuvier's 'law', long held to be sacrosanct though now known to be invalid. Thus, a carnivorous animal must have claws to hold its prey, and teeth suitable for tearing the flesh; it must have a digestive system that can deal effectively with such a diet; and arrangements of limbs and feet to give sufficient speed for successful pursuit. These in turn imply appropriate musculature, and appropriate shoulder and pelvic girdles. The visual organs must be efficient, and the brain must have an appropriate level of perception for the catching of live prey.

Cuvier and his followers thus believed that the nature of an animal could be deduced from consideration of one of its bones, and the practice of this comparative anatomy enabled him to complete the partial skeletons of many of his fossil mammals, and to make for the first time logical and accurate restorations of them.

Nevertheless, while acting on this belief, Cuvier made several mistakes. Gideon Mantell, the Sussex physician and palaeontologist, was the pioneer in the investigation of dinosaurs, after his wife's discovery of the first known teeth of this kind in 1822. He searched assiduously for bones that might belong to the animal from which the teeth came; he found many possibilities and sent some of them to Cuvier for identification. Cuvier said that some were from the hippopotamus and others from the rhinoceros; ultimately they

proved to be from the same dinosaur as the teeth (figure 2). Although Cuvier had, in fact, accepted them as bones of herbivores, his mistaken impression that they were mammal rather than reptile was presumably based on his lack of belief in Mantell's geological accuracy. Again, hollow bones sent to him from Sussex were identified as those of a heron-like bird already named *Ardea*; they have subsequently been proved to be from pterodactyls. Nevertheless, Cuvier had his British successes, too, and on his visit to Oxford in 1818 he was rightly able to assure Buckland of the mammalian identity of some jaws from the Jurassic.

The final disproof of Cuvier's law has come since his death. What would he have thought of *Archaeopteryx*, the bird with an almost reptilian skeleton and non-pneumatic bones? Or of the Chalicotheres of the Miocene of Asia, America, and Europe, which, as exemplified by *Moropus* (figure 4), have many of the characters of the hippopotamus, the proportions of some horses, and sheathed claws? There is, however, a general truth in his law, since some phenotypic characters do show a high degree of association.

Cuvier's studies in the Paris Basin were remarkable for their method as well as for their detail: however, the complexity and diversity of what he saw did not lead him to abandon his belief in a series of catastrophes as the determinants of palaeontological distribution; and he never gave up his belief in the fixity of species. Nevertheless, the application of his comparative anatomy to the reconstruction of fossils was to form one of the foundations of evolutionary theory.

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Some consequences of neutron resonance

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The interpretation of absorption spectra in terms of quantized transitions of the atom from one energy state to another is now generally understood. More recent, and therefore less familiar, is the discovery of an analogous interaction between a neutron, behaving as though it were a wave, and an atomic nucleus. This article reviews some of the consequences, both theoretical and practical, of resonance between the nucleus and neutron waves.

The details of the reaction rates between neutrons and nuclei are important in several branches of physics. For example, in fundamental nuclear physics, they give information about the structure of the nucleus. In the theory of the formation of the elements, knowledge of neutron reaction rates is essential for a quantitative assessment of how the heavier elements were produced. In addition, they are of technological significance because of their importance in the theory of nuclear reactors.

In a physical system, the rate of reaction between neutrons and nuclei is governed by three factors—the density of nuclei in the system, the density of neutrons, and the ‘cross section’ for the reaction. The last quantity is a measure of the probability that a single neutron and a nucleus interact in the specified manner.¹ It is a quantity such that the reaction rate is the same as it would be if the nucleus were actually a sphere of the given cross section and the reaction occurred on the impact of a neutron with this sphere. It must, however, be remembered that the reaction cross section will in general vary with neutron velocity and may be very different from the geometrical cross section usually assumed for a nucleus. In this article we shall base the discussion of neutron reaction rates on this important concept of cross section.

FEATURES OF NEUTRON CROSS SECTIONS

Two peculiar and important features of nuclear reactions involving particles with low and moderate energies are the strong dependence of the cross section on energy and the way in which it fluctuates. An example of this behaviour is provided by the total neutron cross section of uranium 238; figure 1 shows this as a function of energy. If neutrons could be regarded as point particles and nuclei as spheres of radius R to which the

bombarding neutrons stick, or by which they are scattered, the total cross section would be independent of energy and would have the value πR^2 . For an average nucleus, this is about $1-2 \times 10^{-24} \text{ cm}^2$, and this value is approached in the case of very fast neutrons having energies of tens of million electron-volts. When low-energy neutrons bombard uranium, however, the cross section at most neutron energies is about four times the above

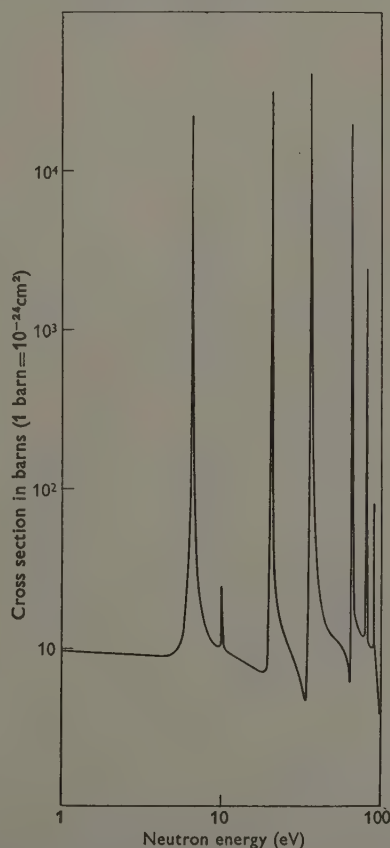


FIGURE 1—The total neutron cross section of U^{238} as a function of neutron energy from 1 eV to 100 eV.

¹ The precise definition of the cross section for a reaction is the ratio of the number of events occurring per nucleus per unit time to the number of neutrons passing through unit area per unit time.

value, and the curve shows many narrow peaks rising to several orders of magnitude above the value predicted by classical theory. This phenomenon arises from the wave-particle duality of matter. The neutron-nucleus system has such very small dimensions that a slow neutron falling on a nucleus must be considered as a wave; the cross section of a wave falling on a small non-resonant sphere of radius R is $4\pi R^2$. The narrow peaks in the cross-section curve represent resonance of the neutron wave with the nucleus; the wavelength depends on momentum, and hence on energy, and is governed by the de Broglie relationship.

This resonance between the nucleus and neutron waves of definite wavelength is closely analogous to the lines found in the absorption spectra of atoms subjected to electromagnetic radiation, such as visible light or X-rays. An important result of quantum mechanics is that the energy of an atom is quantized into discrete values: an absorption line is interpreted as the transition of an atom from its lowest (ground) energy to some higher state by absorption of a quantum of radiation equal to the energy difference between the two states. In the neutron-nucleus system also, a transition to another energy state occurs at resonance. There is the important difference, however, that absorption of the neutron has occurred, so that the new energy state is that of a different, 'compound' nucleus: this is about one mass-unit heavier than the target nucleus but has the same charge. Thus neutron-resonance measurements can give information about the excited states of nuclei just as absorption spectra can give information about the excited states of atoms.

DEDUCTION OF NUCLEAR PROPERTIES FROM NEUTRON CROSS SECTIONS

What is the excitation energy of the states observed in neutron reactions? It is certainly not the neutron energy, for this merely gives the difference in energy between the ground state of the target and the resonance state of the compound-nucleus. What we want to do is to refer the energy of the excited compound-nucleus to the ground state of the same nucleus, and to do this we must turn to the study of nuclear masses. It has long been established that the mass of a nucleus is not precisely equal to the sum of the masses of its constituent neutrons and protons. This mass defect is explained by the equivalence of mass and energy. To separate all the nucleons (neutrons and protons) against the forces that bind them requires energy equivalent to the mass defect of

the nucleus. There must be a corresponding mass defect in molecular and atomic systems, but it is too small to be observable: in nuclei, however, it is proportionately such a large effect that measurement of nuclear masses provides a method of determining nuclear binding energies.

It has been found that to remove one neutron from a nucleus in its ground state requires energy of several MeV, the actual quantity varying according to the nature of the particular nucleus. For nuclei not subject to radioactive decay—those having approximately equal numbers of neutrons and protons among the light nuclei, and those having a considerable neutron excess among the heavy nuclei—the neutron separation energy averages 7–8 MeV, being rather higher than this in the iron region of the Periodic Table and less near uranium. As we move away from the region of stable nuclei towards neutron-rich nuclei, the neutron-separation energy decreases rapidly. The neutron-rich nuclei are generally β -active, decaying by electron emission and increasing their electric charge by one unit in the process. More detailed study of nuclear masses reveals that at certain places among the stable nuclei there are sharp discontinuities in the values of the separation energy. Nuclei containing 8, 20, 28, 50, 82, and 126 neutrons have high separation energies: these numbers have been called the 'magic' numbers. Nuclei with just over a magic number of neutrons have small separation energies. For example, $^{126}_{82}\text{Pb}^{208}$ and $^{127}_{82}\text{Pb}^{209}$ have separation energies of 7.37 and 3.86 MeV respectively. The stability of magic-number nuclei is analogous to the chemical stability of the noble gases, and their properties have been explained by a similar quantum-mechanical theory, based on a shell model of the nucleus [10].

It is now apparent that the neutron-excited compound nucleus differs in energy from the same nucleus in the ground state by an amount equal to the kinetic energy of the neutron plus the separation energy of the compound nucleus. The energy relations are made clearer in figure 2, where a comparison with atomic absorption is also made. One of the first revelations of neutron-absorption measurements is the average spacing of energy levels of nuclei at excitation energies of the order of several MeV. Theoretically, the resonance spacing should decrease markedly with increasing excitation energy, and there should also be a strong dependence on the number of nucleons in the nucleus. Measurements of low-energy-neutron cross sections agree with theory. Resonance spacings are very large (several hundred keV)

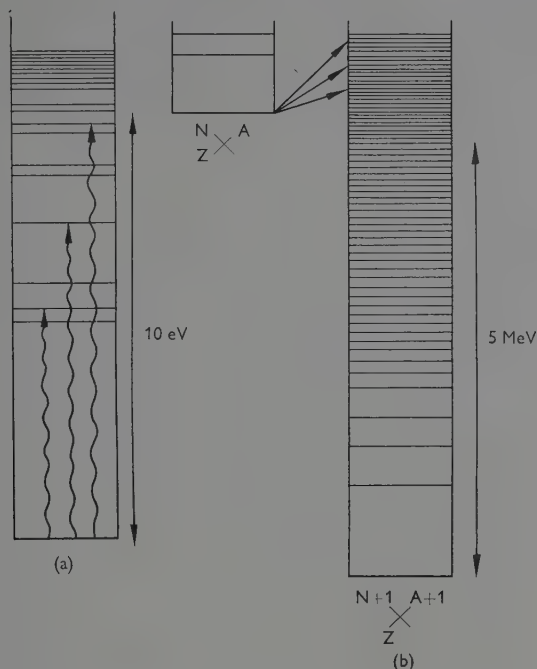


FIGURE 2—Energy-level diagrams illustrating (a) the absorption of electromagnetic radiation (wavy lines) by an atom, and (b) the absorption of a neutron by a nucleus. The ground state of the target nucleus (denoted by $\begin{smallmatrix} N \\ Z \end{smallmatrix} \times A$) is at an energy level equal to the ground-state energy of the target plus the energy of a free neutron at rest. The arrows indicate the increase in energy due to the kinetic energy of the neutron.

in the cross sections of light nuclei. They decrease with increasing mass number until they are about 10 eV at mass numbers greater than 100. Thereafter, the decreasing neutron-separation energy almost balances the effect of the increasing number of nucleons. Notable departures from this overall trend have been observed near the magic-number nuclei, where the resonance spacing can be several orders of magnitude greater than average. Such effects provide valuable confirmatory evidence for the shell theory of the nucleus and assist the understanding of nuclear behaviour.

The excited states that result from neutron absorption subsequently decay. Decay is often by a cascade of electromagnetic radiation (γ -rays), the system jumping through a series of lower states, emitting energy at each jump, until it reaches the ground state of the compound nucleus. Decay may also take place by emission of a neutron having the same energy as the incident neutron: this is known as elastic scattering. If the energy of the excited state is high enough, decay may take

place by emission of a neutron having much lower energy. The target nucleus is then left in an excited state, which decays by emitting a γ -ray: this is inelastic scattering. Decay may even take place by the loss of a proton or other charged particle, and the residual nucleus is then neither the target nor the compound nucleus (figure 3).

In the region of a resonance, the dependence of the cross section on energy can usually be expressed mathematically in a form known as the Breit-Wigner formula, involving the resonance energy and quantities known as the partial widths: the latter are inversely proportional to the lifetimes of the different decay-processes and are important characteristics of the state. The sum of the partial widths is equal to the width of the resonance peak, and their ratios are those of the partial cross sections for the different events. For example, the neutron and radiation widths of a resonance are proportional to the elastic-scattering and radiative-capture cross sections at resonance.

In fundamental nuclear physics, most study has

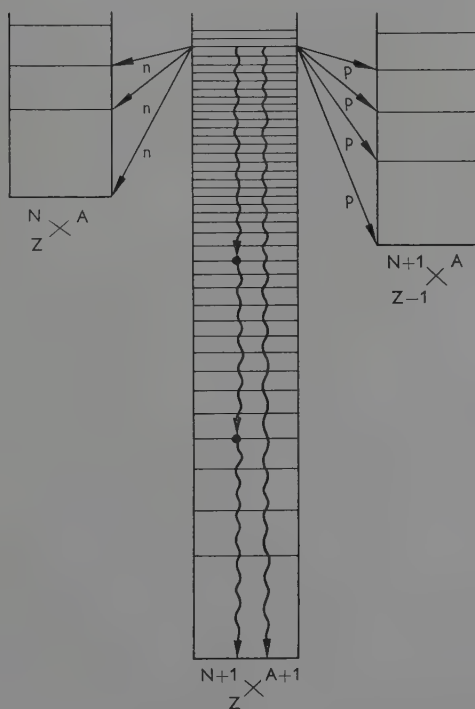


FIGURE 3—Energy-level diagram illustrating decay of the compound nucleus by neutron emission, proton emission, and electromagnetic radiation. In the latter case (left) a typical cascade is shown, as well as a single transition to the ground state of the compound.

been directed to the process of decay by elastic scattering. A wide survey of this aspect of low-energy-neutron cross sections has given important information on some general properties of nuclear matter [1]. It must be concluded that the nucleus behaves towards neutrons as if it were optically a highly refractive medium with a slightly diffuse boundary and a small degree of opacity. The mean free path of neutrons in the medium, about 5×10^{-12} cm, is a measure of the opacity: this is to be contrasted with the nuclear radius, which varies between 10^{-13} and 10^{-12} cm. The opacity may be less at the magic numbers [3]. It has even been possible to infer something about the shape of nuclei. In the mass-number range 140–200 it is necessary to assume an ellipsoidal shape for the nuclei [2]; this corroborates a considerable body of evidence, from other fields of nuclear physics, that many nuclei are not spherical.

THE ROLE OF NEUTRONS IN THE FORMATION OF THE ELEMENTS

Cosmological theories are required, among other things, to give a satisfactory explanation of the observed abundance of the elements. Some theories of nucleogenesis have assumed that the elements appeared at a very early stage in the development of the universe. The most satisfactory theory at present seems to be that much, if not the greater part, of the formation of the elements has occurred, and is occurring, in the stars.

According to this view, advanced by E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle [4], the lighter elements are formed principally in charged-particle reactions. Since the combination of particles of like charge requires considerable kinetic energy to overcome their electrostatic repulsion, such reactions can proceed only in stars at a high temperature. In the initial series of reactions, proton burning takes place, with the eventual formation of helium. At this stage, and at the end of subsequent stages involving heavier elements, the electrostatic repulsion of the nuclei produced is too great to allow any further reactions to proceed at the existing temperature of the star. However, gravitational contraction then takes place and the potential energy released is converted to kinetic energy of the nuclei, raising the star temperature and allowing the next reaction to proceed. Helium burning follows hydrogen burning and produces simple nuclei of the α -particle type, that is, those containing even numbers of both protons and neutrons: examples are carbon, oxygen, and neon. After

this, the star temperature becomes so high that the electromagnetic radiation present can initiate (γ , α) reactions. The resulting release of α -particles allows the formation of higher elements of the α -particle type up to Ca^{40} and even Ti^{48} .

The formation of nuclei other than those of the α -particle type implies that burnt material is ejected from a star into hydrogen, which then becomes sufficiently heated to react. Thus protons reacting with C^{12} will give C^{13} and N^{14} , and with Ne^{20} will give Na^{21} , which decays by positron emission to Ne^{21} . The reaction of α -particles with C^{13} and Ne^{21} liberates neutrons, and a variety of nuclear reactions may then take place, especially at high temperatures. A star held for a sufficiently long period at a temperature greater than about 3×10^9 °C would be converted entirely to Fe^{56} , the most stable of all nuclei and

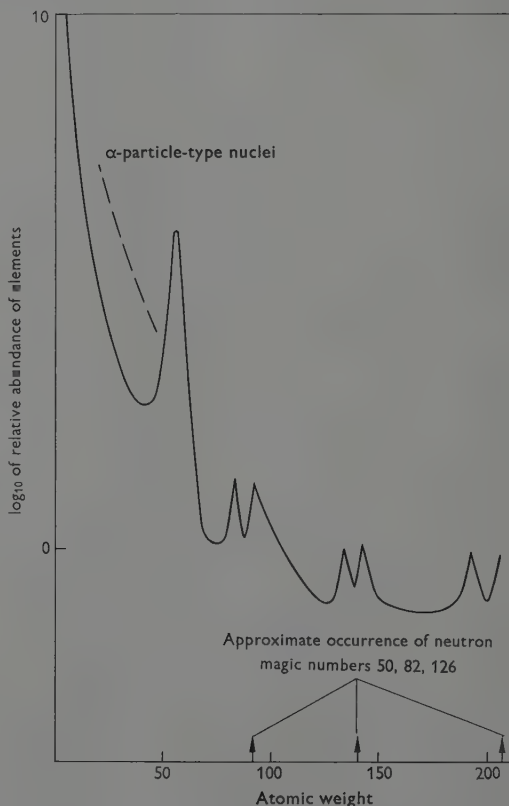


FIGURE 4 – Representation of Suess and Urey's values [5] for the abundance of the elements. Note the high abundance of the nuclei of the α -particle type, the large peak in the region of Fe^{56} , and the double peaks associated with each neutron magic number above Fe^{56} . The proton-rich heavy nuclei lie much lower and are not shown.

therefore the ultimate product of any series of energy-producing nuclear reactions. That this equilibrium process has taken place to some degree is supported by the carefully assessed values for the abundances of the elements that H. E. Suess and H. C. Urey have presented [5]: a curve relating abundance to mass number is shown in figure 4.

The formation of the heavy elements is principally due to neutron capture, the source of the neutrons being reactions such as $\text{Ne}^{21} (\gamma, n) \text{Ne}^{20}$ and $\text{Mg}^{25} (\gamma, n) \text{Mg}^{24}$. Two distinct mechanisms of neutron capture (s- and r-processes) are thought to be involved. The 'slow' or s-process is believed to take place in the interior of red-giant stars, where the temperature is about 10^8 °C. Neutron capture takes place here so slowly that the formation of a β -radioactive nucleus will usually be followed by its decay before further neutron addition is likely (figure 5). The nuclei produced lie close to the natural stability line (defined, at each mass number, by the nuclide having the maximum binding energy per nucleon). If equilibrium is attained among the members of a chain of nuclei formed in the s-process, the rate of formation of a given nucleus is equal to the rate of its removal by further neutron addition. The product of the number of nuclei of a given species and its capture cross section is then a constant for

all members of the chain. Even if equilibrium is not attained, this product should be a smoothly decreasing function of mass number.

The 'rapid' or r-process of neutron capture is believed to take place in the sudden and brief stellar cataclysms that result in supernovae. The rapid and enormous flare-up associated with these stars has been observed three times in the last millennium, the first having been recorded by the Chinese in A.D. 1054. Conditions of extreme temperature and enormous neutron-flux are believed to exist in supernovae, and neutron capture takes place too rapidly for β -decay to occur before further neutron capture. Increasing incorporation of neutrons in a nucleus is eventually halted, however, by the decrease in the neutron separation energy; this allows the inverse photoneutron reactions to set up equilibrium with neutron capture at certain points in the chain. At these points the process halts until β -decay occurs. The resulting nucleus, of higher charge and lower neutron-excess, then proceeds to capture neutrons again (figure 5). A special effect occurs at neutron magic numbers: here the neutron separation energy falls abruptly so that a 'spiral staircase' effect occurs (figure 5), one neutron capture being followed by a pause for one β -decay. The β -decay lifetime increases towards the top of the staircase, and consequently there is a piling up of the stable nuclei which are neutron-rich and have nearly-magic numbers. This effect accounts for the lower mass-number peak associated with each neutron magic number in the abundance curve for the elements (figure 4). These peaks are strong evidence for the occurrence of the r-process.

A knowledge of average neutron-capture cross sections at an energy equivalent to the interior temperature of a red-giant star (corresponding to 10–20 keV neutron energy) is required to test the s-process theory. A great effort has been made to measure these cross sections, but present methods are limited in their scope. However, a knowledge of the properties of neutron resonances at low energies can be used to deduce theoretically the average capture cross section at higher energies, often with considerable accuracy [6]. For example, the calculated and experimental capture cross sections for U^{238} up to 700 keV neutron energy are shown in figure 6. At neutron magic numbers the average capture cross section is particularly small. The smooth variation of the product of cross section and abundance of the s-process nuclei implies an abundance of nuclei having a normal neutron-proton ratio and a magic number

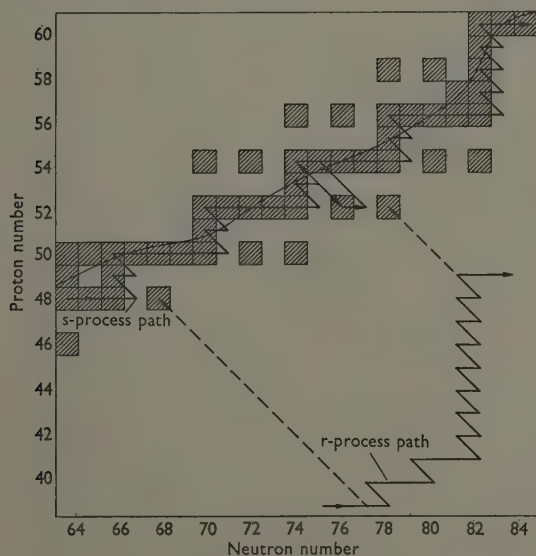


FIGURE 5.—Comparison of the slow and rapid neutron-capture processes. The stable nuclei are shown as hatched squares. \nwarrow indicates a β -decay, \nearrow indicates positron emission, \rightarrow indicates a neutron capture. \nwarrow indicates examples of subsequent β -decay of the nuclei formed in the r-process, leaving finally the neutron-rich stable nuclei.

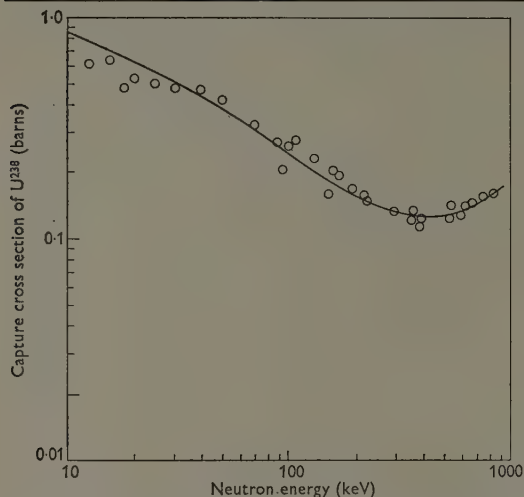


FIGURE 6—The average neutron capture cross section of U^{238} from 10 keV to 1 MeV. The full curve is calculated from information deduced from a study of the low-energy resonances in the U^{238} neutron cross section.

of neutrons: peaks corresponding to such nuclei are indeed observed in the abundance curve.

The r-process is not so dependent as the s-process on neutron cross section. Further knowledge of cross sections for neutron capture and for fission is necessary, however, to deduce much about the formation of the very heavy elements (above $A \approx 209$), where the s-process ceases because of α -decay. The r-process is believed to terminate with the formation of nuclei, such as Cf^{254} , which are spontaneously fissile with short half-lives. The energy released in fission is so great (about 200 MeV) that the r-process would be expected to yield a large proportion of the observed energy release of supernovae. The important observation that the rate of decay of the light output from supernovae corresponds to the half-life of Cf^{254} (55 days) lends support to this theory. However, it is to be noted that other interpretations of the half-life of supernovae can be made. One rival theory, for example, ascribes supernovae to hydrogen-burning thermonuclear explosions, the decay of Be^7 (56 days) accounting for the rate of diminution of light intensity [7]. More data are necessary to solve this problem, and there is no doubt that these studies can yield much knowledge of great interest to both nuclear physics and astrophysics. For example, additional relevant information has been obtained from the formation of neutron-rich heavy elements in terrestrial thermonuclear explosions. The observed rates of

formation of the heavy elements give information on their neutron-capture cross sections. These values suggest that the separation energies of the neutron-rich nuclei are surprisingly high [8].

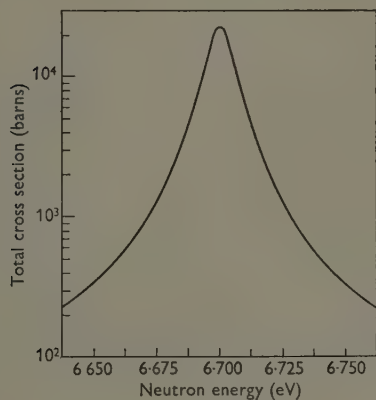
SOME ASPECTS OF NUCLEAR REACTOR THEORY

The detailed resonance-behaviour of neutron cross sections has important consequences in reactor physics, but before discussing some of the interesting effects it will be helpful first to summarize the relevant basic principles of a natural-uranium reactor. In the neutron-induced fission of a heavy nucleus there is a tremendous energy release associated with the splitting of the nucleus into two roughly equal parts and the liberation of a few neutrons having an average energy of about 2 MeV. The release of these is crucial, for they may induce further fission, so initiating an energy-producing chain reaction. U^{238} (present to the extent of 99.3 per cent in natural uranium) is fissionable at an appreciable rate by fast neutrons (energy greater than about 1 MeV), but at this energy, inelastic scattering is also important. Consequently most neutrons are rapidly slowed to below the fission threshold of U^{238} : any fission in U^{235} is usually negligible, because of its very low concentration (0.7 per cent) in the natural element. If the neutrons are slowed down sufficiently—for example, by collision with light nuclei such as carbon or deuterium—they attain thermal equilibrium with their surroundings and will then have an average energy of about 0.025 eV in material at room temperature. There will now be an appreciable rate of fission of the U^{235} nuclei, as the fission cross section of U^{235} is high at very low neutron-energies because of strong resonances.

Resonance properties also affect the slowing (moderating) of neutrons from their high energy they possess at creation to the thermal energies at which they can induce further fission. During moderation some neutrons may be captured by U^{238} nuclei in the fuel, thus decreasing the rate at which the chain reaction proceeds. Since the capture cross section for U^{238} is confined to narrow resonance bands, the neutrons are slowed by a series of resonance traps. In the moderating process the neutron loses, on the average, a given fraction of its energy in each collision; this means that a neutron must make a greater number of collisions to cross a low-energy resonance-trap of given width than a high-energy trap. Because the low-energy resonances tend to correspond with larger capture cross-sections they are of great importance in the

slowing-down process. Nevertheless, even resonances above 1 keV neutron energy are not negligible in the neutron-capture process [9].

To lessen the effect of this neutron capture it is desirable to separate as far as possible the moderating material and the fuel: embedding fuel rods in the moderator reduces the resonance capture because of a self-screening effect, illustrated in figure 7. Figure 7(a) shows a typical resonance cross section for capture; in figures 7(b), (c), and (d), the transmission of neutrons through increasingly thick slabs of material is shown. It is apparent that neutrons of the resonance energy are not transmitted beyond a certain critical thickness: in other words, the capturing material beyond this critical thickness does not contribute to the capture of resonance-energy neutrons. The neutron capture, integrated over the resonance, is shown as a function of slab thickness in figure 8:

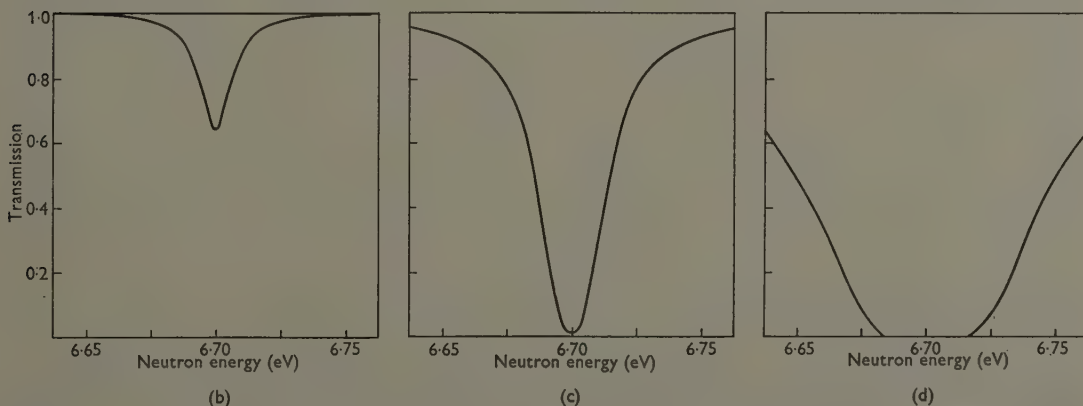


(a)

the departure from linearity shows why it is advantageous to lump the fuel in a reactor.

So far, our discussion of neutron-resonance cross sections as a function of energy has implicitly assumed that the bombarded nucleus is at rest, so that it is only the energy or velocity of the neutron that needs to be considered. In practice, of course, the atoms themselves are in thermal motion, so that neutrons with a definite energy will have different velocities with respect to the different nuclei in an assembly of atoms. Because of this, each nucleus will have a different cross section for neutrons having uniform energy, depending on the energy corresponding to the relative motion between nucleus and neutron. The effective cross section of nuclei in the assembly is obtained by averaging these cross sections over all the different possible relative velocities allowed by the thermal motion. Near the narrow resonances of heavy nuclei, the effective cross sections can differ very greatly from the stationary-nucleus values: a typical case is illustrated in figure 9. The extra broadening of the resonance in the effective cross section is known as Doppler broadening.

Doppler broadening is important in considering the safety of a reactor. Clearly, the broadening and lowering of the peak height of an effective resonance cross section increases with rising temperature, and this results in lowered self-screening to neutrons in bulk matter. The effect of this on the operation of a natural-uranium reactor is as follows. If the reaction rate is increasing, the temperature will tend to rise. As the temperature rises, the self-screening effect of the U^{238} -capture resonances drops, and there is an increase in the rate of capture of neutrons during moderation,



(b)

(c)

(d)

FIGURE 7 - The cross section for a typical capture resonance (a) and the resulting transmission of a beam of neutrons through increasingly thick slabs of material as functions of energy; (b) corresponds to a slab containing 2×10^{19} nuclei per cm^2 , (c) 2×10^{20} nuclei per cm^2 , and (d) 2×10^{21} nuclei per cm^2 .

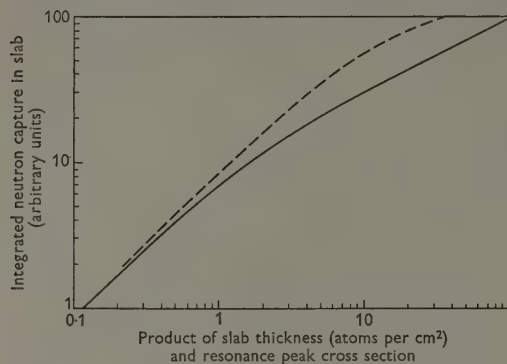


FIGURE 8 - The integrated neutron-capture in a beam of neutrons passing through a slab of material with a resonance in its capture cross section. The capture is plotted against slab thickness, and shows the self-screening effect of bulk material. The full line is for a material where temperature-broadening of the effective cross section is negligible. The broken line is typical of the case where temperature-broadening is important; it corresponds, for example, to the 6.7 eV resonance of U^{238} at about 1500° C.

leaving fewer neutrons to reach thermal energies and carry on the fission process. The result is a braking action on the reactor; the Doppler effect gives the rate of the reaction a negative temperature-coefficient, a very desirable characteristic from the point of view of safety.

This simple consideration of the effect of temperature coefficient does not hold for enriched-fuel reactors: for these, other empirically known, and qualitatively understood, features of resonances must be taken into account. First it must be recognised that not only will capture take place in the non-fissile component of the fuel (U^{238} or Th^{232}) during the neutron-slowness process, but that both capture and fission will also occur in the resonances of the fissile isotope that is present. An extreme case is that of a hypothetical, purely fissile, fuel having uniform resonances each of the same width and with the same ratio of capture cross section to fission cross section. As the temperature increases, the self-screening decreases and the rate of absorption in the resonance region increases. Whether the overall reaction-rate in-

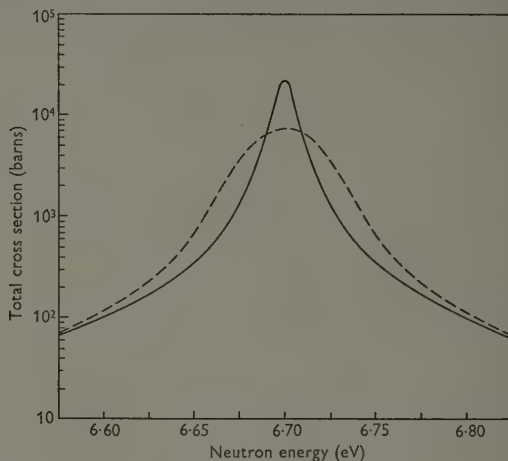


FIGURE 9 - Comparison of the true cross section over a resonance for a stationary nucleus (solid line) with the Doppler-broadened effective cross section in an actual assembly of nuclei (broken line). This example is the 6.7 eV resonance of U^{238} , the uranium being at room temperature.

creases or decreases depends on how the resonance absorption is divided between fission (neutron production) and capture (neutron removal). If fission is predominant in the resonance region, neutrons are added to the system at an increased rate and tend to give the reactor an undesirable positive temperature coefficient. To prevent this, it is necessary to introduce non-fissile material, such as U^{238} , which has narrow capture resonances. Calculation of the amount of U^{238} required is complicated, because the resonances in the cross sections of both fissile and non-fissile isotopes are far from uniform. The radiation widths are usually very nearly equal from one resonance to the next but the fission widths fluctuate wildly. This is fortunate, for it implies that the narrowest resonances in the cross section of the fissile isotope have the largest ratio of capture to fission. Hence the capture resonances are most affected by temperature, and there is a tendency for the rate of neutron loss by capture to increase more rapidly with temperature than the rate of production of neutrons by fission.

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Outdoor aerobiology

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Aerobiology—the study of micro-organisms in the atmosphere—has two main subdivisions. Intra-mural aerobiology is concerned primarily with air-hygiene: extra-mural aerobiology is mainly the concern of plant pathologists and allergists. This article is concerned with the second of these subdivisions. It reviews recent research on the sampling and investigation of the air-borne spores, bacteria, and pollen. Techniques evolved in these studies will be of great importance in the detection of micro-organisms in space and in the atmospheres of other planets.

To the sufferer from hay-fever there will be nothing novel in the idea that outdoor air contains the pollen of many different kinds of flowering plants. But the air also contains many other particles of biological origin, such as the spores of cryptogams, fungi, bacteria, and yeasts, and also protozoan cysts, some of which may also cause allergies. Some species in all the major taxonomic groups of plants have evolved means of introducing their spores into the turbulent layers of the atmosphere [5]. Other organisms, however, are adapted to other dispersal routes, such as water or animal transport, and their spores seldom get into the air.

The systematic study of the microbiology of the atmosphere started about a century ago, in the expectation of finding the source of epidemic diseases such as cholera and typhoid. It is now clear, however, that outdoor air is not a serious source of human infection and it has been acquitted of complicity in the worst human and animal diseases, though recent American work shows that the agents of histoplasmosis and other fungus diseases of man are wind-borne. Outdoor air also conveys pollen, a major nuisance to hay-fever victims, and also infective spores of many important crop pathogens, such as the rusts and smuts of cereals.

In effect, aerobiology began at the *Observatoire Montsouris* in Paris with the work of the bacteriologist Pierre Miquel (1850–1922), who elaborated techniques that enabled him, throughout the last quarter of the nineteenth century, to analyse daily the microbial content of outdoor air. However, the first to attempt consciously to develop aerobiology as an individual branch of science was a plant pathologist, Roger Meier (1893–1938). Unfortunately he was lost on a flight over the Pacific after publishing no more than a few preliminary papers; these papers served, however, to kindle an interest in the subject in the United

States. Also noteworthy in the history of aerobiology was a thesis published in 1935 by K. M. Stepanov of Leningrad [8]. From research based on the work of these and others during three generations it is possible—though our information is still meagre—to picture the circulation of plant spores and other microbes in the atmosphere, and to assess its bearing on medicine, agriculture, and the biological sciences.

TECHNIQUES OF AEROBIOLOGY

Much has been learned about the microbial flora of the atmosphere (here termed the ‘air-spora’ and taken to include the pollen of flowering plants) by examining deposits on sticky-surface traps exposed to the wind. But results obtained by this method are difficult to interpret quantitatively, because the catches depend on factors that vary greatly. For quantitative information about the air-spora it is necessary to use apparatus that removes spores efficiently from a measured volume of air. Such apparatus requires a means of drawing a measured volume of air through a filter, or of accelerating the air so that particles carried in it adhere to a sticky surface or are trapped in liquid.

Suction to draw a measured volume of air through the filter medium is required by sampling devices such as Pasteur’s aspirated plug filter and the newer membrane filters. Another series of devices act by forcing the air through a narrow jet and directing it towards a sticky surface. The General Electric electrostatic air-sampler applies the dust-collection principle worked out by Oliver Lodge. Each of these sampling devices has its virtues and limitations, but can give quantitative data if properly used. In outdoor work, high accuracy is not usually required at present, as results already obtained show that the spore content of the air differs enormously with place and time.

The results of sampling by different methods are

difficult to compare. Some samplers deposit particles directly on to a microscope slide, where totals of the larger spores and pollen grains can be counted visually and classified. Others allow bacterial and yeast colonies, fungus mycelia, or whole moss plants to develop in culture, and identification of the cultivable fraction of the air-spores can then be more precise. This gain in precision of identification over the visual method is, however, balanced by loss of information about the total number of organisms, some of which may not be viable. A few workers have used both kinds of sampler simultaneously.

THE AIR-SPORA NEAR GROUND LEVEL

Most abundant in numbers near ground level are bacteria and fungus spores. When some abundant species of plant is in flower, pollen may overshadow bacteria and fungi for a time in mass, but even then not usually in number of particles. About 90 per cent of the species of flowering plants are usually insect-pollinated, but only about 10 per cent are adapted for wind pollination and habitually shed their pollen into the air. However, these wind-pollinated species are numerically exceedingly abundant and in the aggregate shed large quantities of pollen, with the result that the unfortunate sufferer from hay-fever who is allergic to certain species of pollen finds his respiratory tract a reliable indicator of flowering dates. In temperate countries there are three main seasons for air-borne pollen. The 'tree pollens' in spring begin with the opening of the catkins of deciduous trees and end with the conifers; fortunately, sensitivity to tree pollen, and especially to pine, is rare. In early summer the grass-pollen season brings the greatest number of hay-fever victims. Late summer brings a mixture generally grouped as 'weed pollens'. These include nettle in Europe and the highly potent pollen of ragweed (*Ambrosia* spp.) in North America; freedom from air-borne ragweed pollen may be as valuable to an American health resort as a high figure for sunshine is in Britain.

Air-borne bacteria can be enumerated only by cultural methods, and because of the technical problems of culture we have no idea how many such bacteria elude detection. It is therefore impossible accurately to compare total numbers of bacteria and fungi in the air. However, it is clear that the numbers of cultivable moulds usually much exceed the numbers of bacteria, and Miquel was clearly embarrassed by the immense numbers of air-borne moulds. His early work suggested 700

bacteria and 30 000 mould-spores per cubic metre; his long-term averages of about 300 bacteria and 200 mould-spores per cubic metre at the *Observatoire Montsouris* were obtained only after he changed over to using sugar-free culture media so as to discourage mould growth, a practice that has been followed by many later workers. The bacteria of the air include many micrococci and bacilli, but also a surprisingly large proportion of kinds that do not form spores.

Visual examination of the fungus spores deposited on a microscope slide during continuous sampling with the Hirst trap in an arable field at Rothamsted Experimental Station [4] shows that the predominant organisms in outdoor air during the day in the warmer months are spores of *Cladosporium*, a genus of saprophytic moulds found on decaying vegetation; the average was 5800 per cubic metre of air near ground level during June to October 1952. This dominance of *Cladosporium* is also true of many other parts of the world, and it is fully confirmed by cultural methods and examination of dust deposits. More study is needed to find out how *Cladosporium* becomes air-borne. Second most abundant in the air-spores at Rothamsted were spores of the type known as ballistospores. The sources of these include the mirror-yeasts (sporobolomycetes) that flourish on the surfaces of living and ageing leaves, mushrooms, and toadstools, averaging 4400 per cubic metre and predominating at night. Recognition of ballistospores as numerically important components of the air-spores was long delayed by two causes. Firstly, these very small spores were inefficiently collected by the sticky-surface traps used in much early aerobiological work, and, secondly, most microbiologists were not familiar with the spores of the higher fungi. Spores of various plant-pathogenic fungi such as the rusts, smuts, and mildews are often present in the air in large numbers, but their occurrence, like that of the pollen of flowering plants, is highly seasonal.

The figures given above are for average frequencies over a period of many weeks of continuous recording. Hourly means are often much higher or lower; for example, *Cladosporium* may reach 100 000 and *Sporobolomyces* about 1 000 000 per cubic metre. There is evidence that shorter-term fluctuation may be still greater: ragweed pollen in spot tests lasting a couple of minutes has given concentrations of over 10 million per cubic metre [2].

Protozoan 'eggs' in the air were estimated by Miquel at 0.1 per cubic metre, but later work by

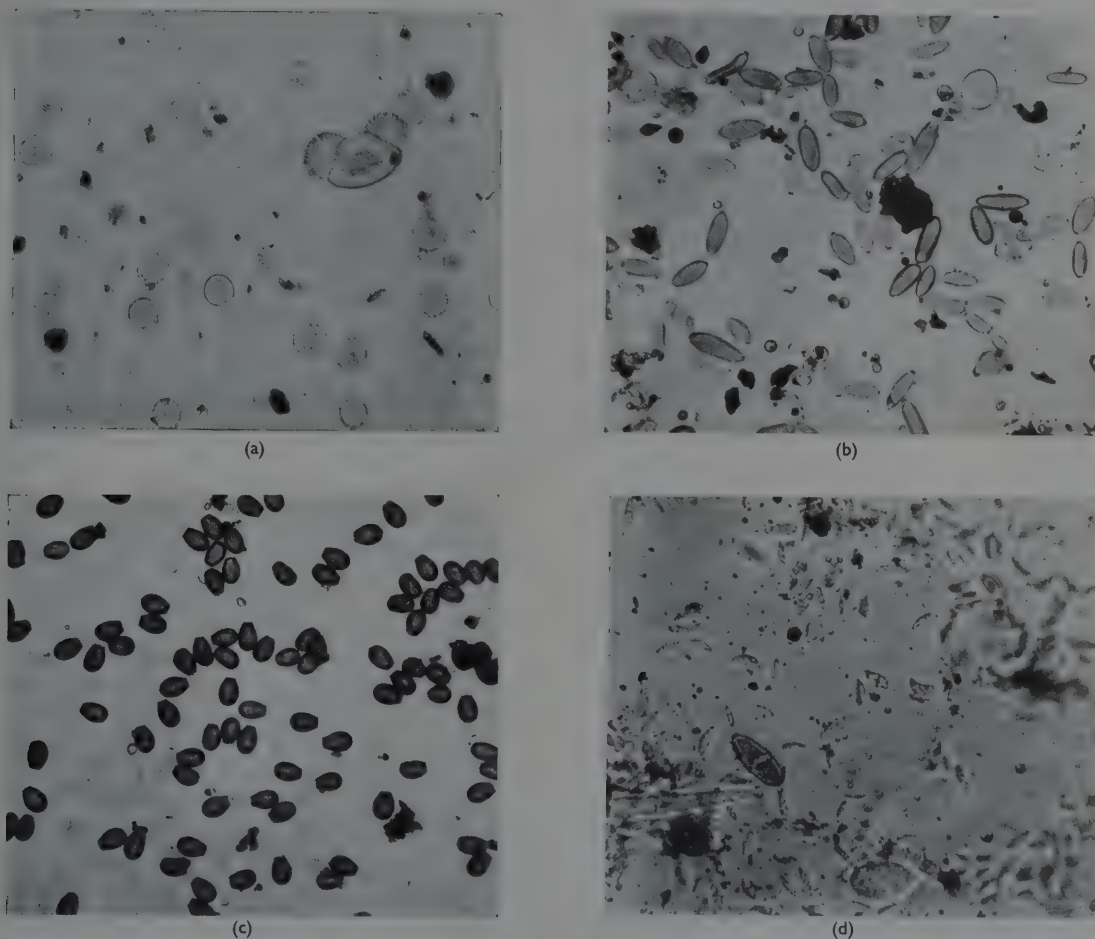


FIGURE 1 — Photomicrographs illustrating pollen and fungus spores in air at 0.5 metre above ground level, beside a stream, at Imperial College Field Station, Sunninghill, Berkshire, summer of 1958. (a) 15th June, 17.00 hrs. Pollen of pine (with two air sacs) and grasses ($\times 230$); (b) 16th June, 10.00 hrs. Spores of the mould *Cladosporium* ($\times 450$); (c) 18th June, 02.30 hrs. Spores of the bracket fungus *Ganoderma applanatum* ($\times 450$); (d) 19th June, 04.00 hrs. Spores of the mirror yeast *Sporobolomyces* ($\times 1000$).

Puschkarew, based on fewer tests, suggests ten times that figure. Blue and blue-green algae may average 1–10 per cubic metre, but spores of myxomycetes are probably less abundant. Spores of ferns and mosses are sometimes plentiful for short periods.

Concentrations of the few organisms that have been studied in detail fluctuate with a characteristic diurnal periodicity, as also does grass pollen. Miquel found two maxima and two minima in the daily cycle of bacterial numbers when sampling hourly at Montsouris for over a year. Nothing similar has been attempted with bacteria since 1884, however, and the work needs extending and repeating.

Spores of fungi show various diurnal periodicities, but normally any one type has only a single daily maximum and minimum. For example, in England spores of *Phytophthora infestans*, the fungus causing potato blight, are most abundant shortly before noon, whereas the numbers of spores of *Cladosporium* and of some rust fungi reach a maximum in the afternoon. Spores of *Sporobolomyces*, and basidiospores of mushrooms, toadstools, and bracket fungi are all most abundant during the night. Little is yet known about differences in these cycles in various parts of the world. These diurnal cycles are clearly determined largely by the effect of meteorological factors on spore liberation and dispersal in ways understood for only

a few species of fungi. Some, such as two important crop pathogens, *Ophiobolus graminis* and *Venturia inaequalis* (causing take-all of wheat and apple scab respectively), depend for spore liberation on the wetting of the substrate by rain or dew; they occur in the air in large numbers only after rain.

THE ORIGIN OF THE AIR-SPORA

Despite claims to the contrary, there is little doubt that most of the air-spores comes from ground sources on the surface, such as plants and vegetable debris, rather than from the soil itself. Only the sources of the protozoa, bacteria, and yeasts (other than the 'mirror-yeasts') remain in doubt. The air-spores are not rich in typical soil inhabitants but represents mainly organisms growing above the surface. Soil and surface dust raised by wind may possibly be the source of most atmospheric bacteria and yeasts, and the seasonal maximum numbers of bacteria in the air of temperate regions seems to be associated with the tilling of bare ground in spring or with strong winds. Splash droplets from marine and fresh water, and from wet soil, evidently help to make surface organisms air-borne.

THE AIR-SPORA OVER THE OCEAN

Samples taken on ships show that, with an offshore wind, the influence of the land-spores often extends to several hundred miles from shore, but that in mid-ocean the air is nearly free from microbial contamination. The proportion of air-borne bacteria requiring sodium chloride for growth is stated to increase in proximity to the ocean. Pollen can sometimes be found in quantity for some miles out to sea, but its concentration usually decreases faster as the land recedes than does the concentration of moulds or bacteria. However, even in mid-ocean, on the coasts of Greenland, and on remote oceanic islands, tree pollen falls regularly in small but measurable quantities after being transported for hundreds or thousands of miles by the wind.

THE UPPER TROPOSPHERE

The presence of pollen and microbes in air layers above ground has been confirmed by catches on kites, balloons, and aeroplanes. Theoretical considerations suggest that spore concentration should decrease logarithmically with height, on the assumption that spores coming into suspension from the ground reach an equilibrium resulting from the rival actions of stirring up by atmospheric turbulence and sedimentation under

gravity. In practice, concentration does at first usually decrease with height above ground level. On some occasions, and more often when several occasions are averaged, the decrease follows approximately the logarithmic law up to a height of several thousands of metres. However, a decrease in concentration according to the logarithmic law is an ideal condition seldom attained in the atmosphere, and in practice a zone of increased concentration often occurs at a height of perhaps two or three thousand metres. This fact has led to speculation about a so-called 'biotic zone' in the upper air, but the explanation probably lies partly in the different histories of air masses at different heights, and partly in the washing of the lower layers of air by rain. Microbial concentration is sometimes high in the bases of clouds, and spores may perhaps become concentrated there by being collected in droplets poised on ascending convection currents in cumulus clouds. The effect of these processes would be particularly noticeable over the ocean, where the air-spores is not constantly being renewed from the surface.

Systematic measurements of spore concentrations at different heights over the oceans have still to be made, but observations made by different methods on ships and from aircraft suggest that the gradient may be the reverse of that over land. Far out to sea, the surface air appears to contain exceptionally few microbes, whereas several thousand metres up, the concentrations of bacteria, fungus spores, and pollens may be considerably greater. Studies by S. M. Pady and co-workers [6, 7], for example, indicate fungus-spore and pollen concentrations of tens to hundreds per cubic metre at 3000 metres above the North Atlantic, whereas G. Erdtmann [3], sampling on board ship, found values only a tenth or a hundredth of these. We thus have a picture of air-masses carrying over the ocean the spore load they acquired during passage over land, and of the lower layers of air being gradually cleared in passage over the sea both by deposition and by scrubbing by rain showers.

It is remarkable that the microbial content of the atmosphere above the troposphere still remains almost uninvestigated. Samples were taken in the stratosphere by the balloon *Explorer II* in 1935, but there seem to have been no later attempts to sample the stratosphere.

CHARACTERS OF THE AERIAL DISTRIBUTION PROCESS

The atmospheric concentrations reported in

earlier paragraphs result from many spore sources. We must now turn to consider the problem of spatial distribution of spores liberated into the air from a single source. Common experience leads us to expect a decrease in contamination of air or of the ground as the horizontal distance from the source increases. This expectation is abundantly borne out in practice [9] and is a phenomenon exploited widely in isolating healthy from diseased crops, hay-fever patients from pollen sources, and seed-crops from foreign wind-borne pollen, which could cause genetic contamination. Plotted on a linear scale, a graph of the decrease of contamination downwind from a point-source of spores at ground level typically gives an exponential-type curve. The mechanisms underlying this characteristic 'infection gradient' are probably, in order of importance: (i) turbulent three-dimensional dilution of the spore- or pollen-laden air mass by spore-free air as the impure air travels downwind; (ii) and appreciable loss of particles from the spore-cloud by deposition on the ground, vegetation, or other surfaces, especially in the early stages of travel when the cloud is concentrated near ground level; and (iii) loss of viability, which may or may not affect the result. In reality, the source is not a point, and its magnitude and shape also affect the dispersal gradient; concentration is higher, and falls off less rapidly, if the source is a sizeable area rather than a point. As would also be expected, raising the source above ground decreases loss from deposition near the origin.

Prediction of the concentration of the spore-cloud after a given distance of travel presupposes both an adequate theoretical treatment of the very difficult problems of atmospheric turbulence and also an adequate quantitative theory of deposition. Different theories now current predict different concentrations at a given distance, but agree generally with observation and experiment in predicting a rapid decrease in concentration with increasing distance from source. For instance, there is evidence that 90 per cent of spores of the wheat bunt fungus *Tilletia tritici* and the clubmoss *Lycopodium*, when liberated just above ground level, are deposited within 100 metres of the source. Theory suggests that smaller particles than these would be deposited less rapidly, but there is little experimental evidence to support this.

A paradox is apparent here. With such a high rate of deposition near the source, the effect of a point source at distances greater than a few hundred metres must be negligible, yet in spite of

this the concentration of micro-organisms in the upper air and for some distance out to sea is substantial. The paradox is probably to be explained by the fact that although the distant tail of the distribution from a single point source is indeed negligible, the quantity in the upper air over the ocean is the sum of the tails of the distributions of all the point sources present on the continent from which the wind has travelled.

The pattern of wind-borne dispersal differs from a Gaussian frequency distribution around a point source by having increased concentrations both very close to the origin and at great distances, balanced by smaller concentrations at intermediate distances [1].

TERMINATION OF THE DISPERSAL PROCESS

Infection gradients of some plant pathogens have been traced over distances of tens or hundreds of kilometres. Spores of some of the cereal-rust fungi migrate annually for many hundreds of miles in India and in the Soviet Union, and over the North American continent a northward migration of wheat-rust spores in early summer is followed by a return migration in autumn. Yet the distribution of the species and races of the rust fungi is not worldwide: oceans and large tracts of mountain and desert seem to present almost uncrossable barriers.

Apart from death by desiccation or irradiation while air-borne, the flight of a microbe ends either by dry deposition on the ground or by washing out of the air by rain, snow, or hail. The phenomenon of wash-out has never been systematically investigated, and sound techniques have still to be worked out. Results from examining hail are particularly unambiguous, because the surfaces of hailstones can be sterilized to eliminate possible contamination from the ground. Falling raindrops sweep up a substantial proportion of the suspended microbes in their path, and all precipitated water brings down from the sky a rich flora of bacteria, algae, spores of fungi and mosses, and pollen. Precipitated water is not sterile, whether collected over the land, the ocean, or the polar regions. Although a spore is most likely to be deposited dry by sedimentation to ground or by impact with a surface within a few hundred metres of take-off, most spores that escape into the free air probably have their flight ended by rain.

Conditions in outer space beyond our atmosphere, as far as they are known, would appear to offer a highly uncongenial environment to

unprotected micro-organisms. If attempts are made to detect viable spores in interplanetary space, special techniques will be required that owe little to the methods of aerobiology. However, experience gained in sampling our own atmosphere can be applied to some of the problems of sampling in the atmospheres of other planets. Conventional methods of sampling aerosols of single bacterial cells indoors are defective when applied to taking samples of large spores from moving air, and we need to develop better sampling methods,

especially for continuous sampling in culture.

The glimpses we now have of the circulation of minute organisms in the atmosphere of our planet with all the implications in agriculture, medicine, and theoretical biology tantalize us by their incompleteness. It is unfortunate that exploration of our atmosphere has scarcely begun, and that we are not yet adequately equipped with technical methods for the task, at a time when the opportunity of probing the atmospheres of other planets is hastening upon us.

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Book reviews

SCIENTIFIC MANPOWER

Britain's Scientific and Technological Manpower, by G. L. Payne. Pp. xiii + 466. Oxford University Press, London. 1960. 45s. net.

Americans are tireless at fact-finding; this book is an example of fact-finding at its best. It is a compendium of information about scientific and technical education in Britain, the numbers being educated, and the deployment of scientists and technologists in industry, education, and the government services. It was prepared at the request of the United States President's Committee on Scientists and Engineers. The book covers, for the United Kingdom, much of the ground covered for the Soviet Union in two recent books (Nicholas de Witt's 'Soviet Professional Manpower' and Alexander Korol's 'Soviet Education for Science and Technology'). It is based on official publications, and collects together in a compact and lucid form a great deal of information which many of us know exists somewhere but we are not quite sure where. Here is a random sample of the information which can be found in this book: the numbers of post-graduate chemists and physicists who migrated from the U.K. to Canada and the U.S.A. from 1950 to 1956; the annual recruitment of scientists and engineers by fifty engineering firms;

the distribution, from 1948 to 1955, among secondary modern, grammar, and direct-grant and independent schools, of children born in 1936; the proportions of university students in Britain who resided in halls, lodgings, and at home, from 1938 to 1958; numbers taking National and Higher National Certificates; an analysis of current building-projects in universities; expenditure on research and development in Britain; the number of inventions from industries, universities, and government departments communicated to the National Research Development Corporation. The data will inevitably become obsolete; but even then the book will be useful as a guide to what sort of data are to be found, for there is a full bibliography. The text summarizes accurately some of the recent discussions of controversial topics in technological education. There is a good index. Altogether this is an admirable reference book. E. ASHBY

FLUID MECHANICS

Course of Theoretical Physics, Vol. VI, Fluid Mechanics, by L. D. Landau and E. M. Lifshitz (translated by J. B. Sykes and W. H. Reid). Pp. x + 536. Pergamon Press Ltd, London. 1959. £5 5s. net.

This work forms volume VI of the 'Course of Theoretical Physics', to be completed in nine volumes, by two

outstanding Russian physicists. It provides an admirable summary of our knowledge of fluid dynamics treated as a branch of theoretical physics rather than as an exercise in mathematical analysis. The subject is expounded with conciseness and clarity, and is dogmatic rather than speculative. Historical references are scanty and are confined mainly to Russian investigators; Zhukovskii and Chaplygin are mentioned (and rightly so), but not Lanchester nor Sir Geoffrey Taylor. The range of the exposition is generous and includes, in addition to the topics usually treated in English works, the dynamics of combustion, relativistic fluid dynamics, and the theory of superfluids. An English reader would need to supplement this work by reference to other works for the mathematical theory, the experimental results, and the aeronautical applications, but the present volume forms a splendid introduction. It will be of great value to university students specializing in fluid mechanics or about to embark on research in this exciting and rapidly expanding field. G. TEMPLE

EXPERIMENTAL PHYSICS

Methods of Experimental Physics, Vol. VI, Solid State Physics, edited by K. Lark-Horovitz and V. A. Johnson, Part A: Preparation, Structure, Mechanical

and Thermal Properties. Pp. xvi + 466. \$11.80. *Part B: Electrical, Magnetic and Optical Properties.* Pp. xiv + 416. \$11. *Academic Press Inc., New York; Academic Books Ltd, London.* 1959.

Although this volume forms part of a series, it is complete in itself, including even a brief discussion of the treatment of errors of observation. The aim of the work is to provide a concise account of the experimental methods used in the investigation of the solid state. It deals with the preparation of specimens and with the measurement of their most important physical properties. The impressive list of contributors, each an expert in his own field, and the skilful and careful editing by the late Professor Lark-Horovitz (to whom these volumes will constitute a lasting memorial) and by Professor Vivian Johnson, have produced an authoritative, wide, and clear survey.

Each chapter has a general introduction and a sketch of the relevant theory before the main experimental methods and techniques are critically reviewed. It is inevitable that the standard should be somewhat uneven in a publication of this sort, some sections being rather diffuse and others too concise. Again, some of the techniques described, such as X-ray diffraction, are extremely well established; their inclusion here is perhaps justified for the sake of completeness. The production is excellent, and almost all the illustrations are clear and useful. Very few printing mistakes have been noticed. All the sections have good bibliographies, some complete, making the book invaluable as a guide to the literature up to 1959. It will be an indispensable reference book in any laboratory engaged on research on solid-state physics and will be consulted with profit also by workers in other branches of physics.

L. PINCHERLE

ELEMENTARY-PARTICLE THEORY

Introduction to Quantum Field Theory by F. Mandl. Pp. vii + 202. *Interscience Publishers Inc., New York; Interscience Publishers Ltd, London.* 1959. 34s. net.

Theory of Elementary Particles, by P. Roman. Pp. xii + 575. *North Holland Publishing Co., Amsterdam.* 1960. 100s. net.

The current theory of elementary particles and their interactions is based on ascribing to each particle a relativistic field filling all space-time; the particles themselves are quantum manifestations of this field. A photon

is a good example: treating Maxwell's electromagnetic field as a dynamical system and using standard quantization procedures, one arrives naturally and simply at a description of a beam of freely travelling photons. The difficulties of the subject begin when one wishes to describe interactions of the various particles and their corresponding fields.

In all these interactions a certain number of physical quantities are conserved, that is, their values remain unchanged during the course of the interaction. These are quantities such as electric charge, total energy, and total angular-momentum. One of the most successful methods in elementary-particle theory is to concentrate on these invariant quantities, to build into the structure of the quantum fields the deeper physical principles which underlie these conservation laws, and then to draw all possible conclusions for future experiments, without committing oneself to any particular form of the interaction force between the particles themselves. It is astonishing how much one can learn and predict with this minimum of theory. In fact the theory's great successes in the last six years have all been along these lines, the parity principle being an outstanding example. Roman's book is devoted to a study of these invariance principles, while Mandl, on the other hand, is concerned with precisely the converse approach. His book is an exposition of the highly successful Feynman-Dyson method for calculating scattering cross-sections once one postulates, by inspired guessing, the possible form of the interaction force.

The two books differ not only in the approach but also in style. Mandl's aim has been to produce a slender volume, sketching, as rapidly as possible, the actual techniques for writing down possible field equations and solving them. Roman's, on the other hand, is relatively a more generous volume, discussing in a leisurely fashion topics such as representations of the four-dimensional orthogonal group, concepts of space- and time-reflection, and possible classification schemes of elementary particles as multiplets; roughly a hundred pages are devoted to considering field equations of non-interacting particles.

All Mandl's material is already to be found in standard texts, such as Jauch and Rohrlich's 'Theory of photons and electrons' and Bogoliubov and Shirkov's 'Introduction to the

theory of quantized fields'; even so, it fills a real need. My only criticism is that the book is not even more slender. I would have liked something half its size, in paper covers, at half the price—a volume which every graduate student might have bought without affecting his decision to invest in one of the larger standard treatises. Another feature I would have welcomed is a tabulated summary of rules for writing S-matrix elements and for calculating transition probabilities.

Roman's best chapter is the first, on the rotation group. The bulk of the book suffers inevitably from the rapid advance of the subject, even though it marshals an impressive number of topics scattered in periodicals. For example, the parity story is bound to remain incomplete until strange-particle decays are understood. Likewise the current theories of isobaric space probably represent a very temporary phase in the evolution of ideas about this subject. Despite the criticisms above, it is a useful and welcome addition to the meagre number of works on invariance principles.

A. SALAM

NUCLEAR PHYSICS

The Many Body Problem. Université de Grenoble; Cours donnés à l'école d'été de physique théorique. 1958. Pp. xv + 675. *Methuen & Co. Ltd, London.* 1959. 100s. net.

This large volume consists of the lecture notes from the 1958 Summer School in Theoretical Physics which was run by the University of Grenoble at Les Houches. The lectures have as a common background the recently developed methods for discussing many-body problems in terms of the interactions between the individual particles. The first article is N. M. Hugenholtz's account of the elegant work he has done in collaboration with L. van Hove on the basic techniques involved in applying perturbation theory to many-fermion systems. This includes the method of graphs and the use of the concept of holes.

Two long chapters by K. A. Brueckner follow. The first gives an account of his attempts to solve the problem of nuclear structure starting from a given two-body interaction. In the other chapter he applies similar methods to liquid He³ and the electron gas.

Further chapters on the fundamental theory are: one by J. R. Schrieffer on the Bardeen-Cooper-Schrieffer theory of superconductivity, and two by

K. Huang on the work he has done with Lee and Yang on the hard-sphere boson gas. Other impressive chapters come from the lectures of B. R. Mottelson on nuclear-shell structure and deformations, D. Bohm on collective co-ordinates, and D. Pines on electrons, plasmons, and phonons. There are many other contributions, but there is space here to mention only the elegant, short, and incisive discussion by V. F. Weisskopf on the physical basis of theories of nuclear matter.

This volume is obviously of great value to anyone seriously interested in any of the various aspects of the many-body problem.

J. HAMILTON

THERMOELECTRICITY

Applications of Thermoelectricity, by H. J. Goldsmid. Pp. xv + 118. Methuen & Co., Ltd, London; John Wiley & Sons Inc., New York. 1960. 10s. 6d. net.

The introduction of semiconductors, instead of metals, as elements for thermocouples has in recent years raised the old science of thermoelectricity from its slumber. Applications in the laboratory and, more exciting, the prospect of revolutionary industrial developments, such as the production of compact silent refrigerators of indefinitely long life, and of reasonably efficient thermoelectric generators (in particular for the direct conversion of solar energy into electricity), have attracted the attention of many physicists and engineers.

There was a need for a book providing a simple introduction to the subject and a survey of what has been achieved so far, and the work under review aims at filling this need. The author has himself made significant contributions to the subject, and he succeeds in giving an excellent survey of present developments and future possibilities. The book is less successful in providing a physical introduction. The main criticism is that the level of knowledge assumed in the reader varies enormously. Whereas the thermoelectric effects are discussed at length in an elementary way, the reader is supposed to know, for instance, what is meant by energy bands in a semiconductor, what are degenerate and non-degenerate semiconductors, donor and acceptor impurities, the reduced Fermi level, and even the Soret thermal-diffusion effect. One may also disagree with the choice and presentation of some of the material, and object, for instance, to the discussion of experiments on the

thermal conductivity of indium antimonide that nobody has succeeded in reproducing.

The book will, however, be useful to young scientists who want to get introduced to thermoelectricity, and will be particularly welcome to those who have already specialized in semiconductor physics. It will be read with profit by anybody who wants to know what is happening in this field.

L. PINCHERLE

CHEMICAL PHYSICS

Advances in Chemical Physics, Vol. II, edited by I. Prigogine. Pp. xi + 414. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. 87s. net.

This is the second volume in a new series in which experts are invited to write comprehensive articles explaining their views on a subject freely and without limitation of space. Critical reviews of this kind, in which adequate space is permitted for an introduction to the subject, are particularly valuable to those who are not directly concerned with the fields discussed.

In the first contribution by J. H. van der Waals and J. C. Platteeuw, a general account of the properties of clathrate solutions is followed by a rigorous statistical-mechanical treatment of their thermodynamic properties and a discussion of heterogeneous equilibria involving clathrate compounds. K. A. Pitzer reviews theories of the intermolecular and intramolecular forces that arise because of correlation of electron motion between non-bonded atoms or molecules. Special emphasis is laid on the various approximations which have been used, and the results are compared with experiment. The contribution by J. S. Rowlinson and M. J. Richardson is concerned with the solubility of solids in compressed gases. The phase diagrams are discussed, and experimental work on a number of systems is reviewed. After a theoretical discussion, the evaluation of the second virial coefficients from the solubility measurements is described and the results are then compared with those obtained by conventional measurements of pressure, volume, and temperature.

Thermodynamics of metallic solutions are discussed by R. A. Oriani, and this is followed by an extensive review of polymerization reactions by M. Szwarc. The initiation, propagation, and termination of polymerization reactions are discussed, and an account

is given of the 'living polymers'. J. Duchesne describes the use of nuclear quadrupole resonance spectra for studying damage to irradiated crystals. There then follows a very lengthy review, by Per-Olov Lowdin, of different approaches to the correlation problem in many-electron quantum mechanics. This article is followed by a bibliographical survey of the subject compiled by H. Yoshizumi. This authoritative review is written on a rather technical level and would not be very illuminating to someone unacquainted with this field. On the other hand, the last contribution by E. Bright Wilson on the problem of barriers to internal rotation in molecules is an extremely clear account of the present position with regard to the method of measuring these barriers and to their interpretation. The relative advantages of the different methods available are explained, the values obtained are described, and the theories of the origin of the potential barriers are critically discussed.

R. E. RICHARDS

INORGANIC CHEMISTRY

Progress in Inorganic Chemistry, Vol. I, edited by F. A. Cotton. Pp. ix + 566. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. 109s. net.

The growing interest in inorganic chemistry throughout the world and the rapid accumulation of important new material in the original literature provides ample justification for the production of this new series of reviews. It should cover all the major fields of current interest in successive volumes, though only seven topics are dealt with here. They range from accounts of the cyclopentadienyl and arene metal compounds, sulphur-nitrogen compounds, and the isocyanide complexes of metals, to largely theoretical articles on metal-ammonia solutions and the effect of inner-orbital splitting on the thermodynamic properties of transition-metal compounds and co-ordination complexes. Structural chemistry is well represented by reviews of the interstitial compounds of graphite and of the structure and properties of mixed metal oxides. The contributors are all authorities in their respective fields and they have addressed themselves primarily to specialists, though a fair proportion of the text is of interest to a considerably wider range of readers. The international character of the

series is reflected in Professor Becke-Goechring's article on sulphur-nitrogen compounds, which is printed in German: it is to be hoped that this character can be maintained and even strengthened. The editor and publishers are to be congratulated on an excellent first volume: it is certain to fulfil its purpose of making recent progress more widely known.

H. J. EMELÉUS

ANALYTICAL CHEMISTRY

Treatise on Analytical Chemistry, Part I, Theory and Practice, Vol. I, edited by I. M. Kolthoff and P. J. Elving, with the assistance of E. B. Sandell. Pp. xxvi+809. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. 133s. net.

This treatise is described as a comprehensive account of analytical chemistry in three parts; part 1 is to deal with analytical chemistry and its methods, part 2, the analytical chemistry of the elements, and part 3, the analytical chemistry of industrial materials.

Section A, the first 93 pages, is concerned with analytical chemistry and its objectives, functions, and limitations; it is an admirably balanced approach to the subject. It is interesting to note that Sandell and Elving still believe that a most serviceable introduction to research in analytical chemistry is a thorough indoctrination in classical gravimetric and titrimetric analysis, including mineral analysis, and that Sandell should later quote from Lundell's classic 1933 address, 'The analysis of things as they are'. Indeed, their philosophy should provide something of an anchor to the professional analyst when he embarks on Section B, on the application of chemical principles to analytical chemistry, for a very large part of this is devoted to an exposition of modern inorganic and physical concepts. In particular this is true of the chapter by Watters on elements and compounds, and that on chemical equilibrium and the thermodynamics of reactions by T. S. Lee. It will be interesting to look back from part 3 when it appears and to note what impact there has been on analytical technique and achievement.

The standard of the contributions is uniformly high, and one wonders only if the project is not too ambitious or the title too restricted. R. C. CHIRNSIDE

INORGANIC CHEMISTRY

Nouveau traité de chimie minérale,

Vol. XVI, edited by P. Pascal. Pp. xxxix+1196. Masson et Cie, Paris. 1960. Paper covers, NFcs. 170; bound NFcs. 185.

This volume is concerned with two very different groups of elements, the halogens, to which about half the text is devoted, and the transition metals manganese, technetium, and rhenium. Seven authors have contributed, and, as in earlier volumes of the series, their treatment of the various elements follows a uniform pattern, which, broadly speaking, involves a description of the elements in turn. Little attention is paid to comparative chemistry. Bibliographies terminate at various dates between 1956 and 1958, and this inevitably means that a number of important recent advances are omitted, particularly in the case of the halogens. The chapters on technetium and rhenium will be particularly valuable, as few summaries of work on these new elements are available. This is indeed an outstanding reference book, particularly as considerable emphasis is placed on physico-chemical aspects of the subject. It is well arranged, critical, and reasonably complete, though not overburdened with excessive detail. It is also unusually well produced. It would be of the utmost value in any library used by senior students or research workers in inorganic chemistry, especially as the French text is easy to follow even by those with an incomplete knowledge of the language.

H. J. EMELÉUS

FREE RADICALS

Formation and Trapping of Free Radicals, edited by A. M. Bass and H. P. Broida. Pp. xvi+522. Academic Press Inc., New York; Academic Books Ltd, London. 1960. 516.

In the last few years our knowledge of free radicals has increased greatly. This is partly a consequence of the use of new techniques, such as paramagnetic resonance spectroscopy, for measuring their properties, and partly because of the development and exploitation of the procedure of freezing them out into inert solids at very low temperatures. In this way they can be kept unchanged for hours, days, or weeks, and studied by a wide variety of methods. The present book, an assembly of articles by a number of experts, describes the methods of producing and isolating free radicals in solid matrices, and of studying them. Books by a number of authors are

always somewhat lacking in coherence, and there is the danger of poor cross-referencing; the possible annoyances are minimized in the present book by a satisfactory index. The choice of contributors ensures that the accounts given are reliable and authoritative. There are sixteen separate articles, and therefore a very broad coverage is provided of this field, which has been so ably studied, in particular, by a group working under the general direction of the two editors of this volume. This interesting book is therefore an essential possession of anyone engaged in this or in a closely related field.

J. W. LINNETT

ORGANIC CHEMISTRY

Technique of Organic Chemistry, Vol. I, Part I, Physical Methods of Organic Chemistry (third completely revised and augmented edition), edited by A. Weissberger. Pp. xii+894+1-24 (index). Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. 148s. net.

The techniques developed by nineteenth-century physicists have now become the basic tools of the twentieth-century chemist, who can now, in addition, avail himself of electronic controlling and recording devices that greatly diminish the probability of errors in the final recording of accurate numerical data. Consequently this volume, with 15 chapters dealing with calorimetry and temperature measurements and with such parts of the old subject of 'properties of matter' as are today applicable to the elucidation of the structures of chemical molecules, is in reality a detailed reference volume of classical experimental physics.

The book starts a new edition of Weissberger's series of reference texts on techniques of organic chemistry. It modernizes many chapters published ten years ago, adds new ones on subjects such as automatic control and automatic recording, and, in four volumes, will increase the bulk of the previous edition by about half. Fortunately the excellent theoretical surveys written by the original contributors have not been shortened, and it maintains its previous standard of comprehensiveness in its references and of typographical excellence, particularly in the clarity of its diagrams. The present edition will maintain the status of the series as authoritative reference works.

W. A. WATERS

NON-BENZENOID COMPOUNDS

Non-benzenoid Aromatic Compounds, edited by D. Ginsburg. Pp. xii+543. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. 135s. net.

Considerable theoretical and practical advances in the chemistry of non-benzenoid aromatic compounds have been made within recent years. The present volume, which is a collection of reviews on various aspects in this field, is therefore a most welcome addition to the chemical literature.

The scope of the book can be judged by the titles of the nine chapters: aromaticity (Craig); cyclobutadiene and related compounds (Baker and McOmie); compounds derived from cyclopentadiene (Pauson); pentalene and heptalene (Bergmann); azulenes (Heilbronner); pathways to azulene (Keller-Schierlein and Heilbronner); tropones and tropolones (Nozoe); cyclo-octatetraene (Raphael); cyclo-polyolefines (Baker and McOmie). Most of the chapters have been written by one of the chief experts in the particular field.

The choice of topics is a sound one, since, although compounds such as cyclobutadiene, pentalene, heptalene, and cyclo-octatetraene, can by no means be considered aromatic, the impetus for the study of these fascinating systems has been provided through interest in aromaticity in organic compounds.

In a rapidly expanding field, it is inevitable that a book will be out of date to some extent by the time that it appears. In the present case, however, this has been kept to a minimum by the short time interval between writing and publication as well as by the inclusion of notes added in proof, a particularly welcome feature. The printing and presentation of formulae are excellent, and the reviewer noted only a few errors. F. SONDHEIMER

CRYSTALLOGRAPHY

General Crystallography, a Brief Compendium, by W. F. de Jong. Pp. 281. W. H. Freeman & Co., Ltd, London. 1959. 38s. net.

This is a truly remarkable book. Into 265 pages the author, with the collaboration of J. Bouman, has endeavoured to compress the whole of crystallography. There are four sections, dealing with geometrical, structural, chemical, and physical, crystallography. Copious references to the

original literature and to other books will enable readers who have difficulty in following the condensed but lucid explanations to find more extended treatments. So many aspects of the subject are treated, even if very briefly, that it will come as a surprise to many chemists, physicists, and mineralogists to discover the wide range covered by crystallography.

The numerous tables and diagrams are well designed, and it is easy to look up half-forgotten facts. For example, the spherical trigonometry needed by the crystallographer is presented in beautifully compact form in the section on geometrical crystallography, where one can also find a useful treatment of stereographic projection, and a table which translates the mineralogists' and structural crystallographers' descriptions of crystal classes.

The author and his collaborators are to be congratulated on presenting such an extensive view of a subject which is sometimes (quite erroneously) regarded as a narrow speciality. M. R. TRUTER

MINERALOGY

Dana's Manual of Mineralogy (17th edition), revised by C. S. Hurlbut, Jr. Pp. xi+609. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London. 1960. 92s. net.

As a general introduction to mineralogy, Dana's Manual has held the field since it first appeared in 1848. Throughout this great length of time, continuous revision, modification, and expansion have kept pace with the developments in the science, and this process is maintained in this edition, appearing only seven years after its predecessor. The principles of crystal chemistry, which relate chemical composition, internal structure, and physical properties, now find a prominent place and form the basis of the description of the mineral groups. The chief physical properties are well presented, but the optical properties are not dealt with—possibly a blemish so far as some geologists are concerned. Important additions to the treatment of crystallography include sections on stereographic projection, the calculation of axial ratios, and the methods of X-ray crystallography. The classification of minerals used in the descriptive part of the book is that employed in the current revision of Dana's classic 'System of Mineralogy'; the silicates are considered in their structural groups, Strunz's nomenclature being adopted.

This edition is a good introduction to the subject for chemists, physicists, geologists, and students of mineralogy.

H. H. READ

EVOLUTION

Evolution of Nervous Control from Primitive Organisms to Man, edited by A. D. Bass. Pp. vii+231. Publication No. 52 of the American Association for the Advancement of Science, Washington, D.C. 1959.

This volume contains some interesting articles but does not live up to its exciting title. Each of the authors describes his own distinguished contribution to the study of the nervous system, but none of them comes to grips with the problem of the evolution of control. The articles by Ladd, Prosser, and Grundfest contain much of the greatest interest for comparative physiologists. Teuber's article is an excellent condensed account of his findings about the defects that are evident with sufficiently detailed study in all functions, even after localized brain lesions. The psychoanalyst, Mirsky, has a lot to say about hypnotism but hardly begins to deal with the subject of evolution of control mechanisms. J. Z. YOUNG

DARWINISM

Genetics and Twentieth Century Darwinism. Cold Spring Harbor Symposia on Quantitative Biology. Pp. xv+321. The Biological Laboratory, Cold Spring Harbor, L.I., New York. 1959. \$8.

If it were necessary to arrange in order of merit the publications whose appearance has been linked with the centenary of the theory of evolution by natural selection, the palm would have to be awarded to this Symposium. It contains some two dozen contributions by authors who are active experimental scientists whose results and opinions no research worker can afford to neglect.

In the space available it is quite impossible to do justice to them all, and it must therefore suffice to mention the first and last only. Under the titles 'Where are we?' and 'The synthetic approach to problems of organic evolution' Professors Ernst Mayr and G. Ledyard Stebbins have contributed papers which are remarkable not only because they serve as a round-up of the chief victories of past research in the field of evolution, but because they never lose sight of the fact that, however much we know of which our predecessors were ignorant,

what remains to be learned is immeasurably more. Food for much thought is provided by pointing out the Achilles heel of natural selection, and also by emphasizing the difference between high selective value, and high adaptive value, achieved by organisms, the former being probably the main road to extinction. There is now no possible excuse left for those who fail to realize that evolution is the result of mutation, recombination of genes, selection, and isolation; that selection, not mutation, directs evolution; and that the origin of general and higher categories results from the continuation of those same processes which begin by producing new varieties and new species.

G. DE BEER

MOLECULAR BIOLOGY

The Molecular Basis of Evolution, by C. B. Anfinsen. Pp. xiii + 228. John Wiley & Sons Inc., New York; Chapman and Hall Ltd, London. 1959. 56s. net.

As a result of discoveries made during recent years it is now becoming possible to discuss heredity and evolution in molecular terms; among these discoveries may especially be noted the recognition that nucleic acid is the carrier of hereditary information; the elucidation of the molecular structure of deoxyribonucleic acid (DNA); the generalization known as the 'one gene, one enzyme hypothesis'; and the development of methods of determining the amino-acid sequences of proteins. It has become almost a truism that, in the last analysis, the phenotype of an organism is an expression of the amino-acid sequences of the proteins it contains, and that these in turn are determined by the sequence of bases in the DNA derived from its parents in sperm and egg. Most of the intermediate stages are still obscure, but within a few years we shall undoubtedly be able to explain in principle how changes in the phenotype follow from changes in the genetic material.

This attractive book is one of the first attempts to make a connected story of this new field, which has come to occupy a central position in biological research. If there are gaps in the story, it is because the author had the courage to write it almost as soon as a coherent theoretical framework had been established, though knowing that future research was bound to modify this framework in many respects. His discussion involves the relation between biochemistry and genetics,

and he assumes in the reader more knowledge of the former than the latter, though in fact the biochemist without previous knowledge of genetics would be well advised to do some homework in this subject before reading the book. The author has been most successful in conveying the excitement of this rapidly developing field, and the book is strongly recommended to biochemists and to others interested in the fundamentals of biology.

J. C. KENDREW

PLANT ANATOMY

The Plant Cell Wall, by P. A. Roelofs. Pp. vii + 335. Gebrüder Borntraeger, Berlin-Nikolassee. 1959. DM 108.

This book forms part of the *Handbuch der Pflanzenanatomie* and is intended to replace an earlier one written by van Wisselingh in 1925. In the generation that has elapsed since then, the subject has made such advances that a total change of method has been needed for its treatment. The aim of this revision has not been completeness but a critical exposition of the present position, without much inquiry into the stages of its development.

The first chapters deal with the chemistry of the cell-wall constituents, particularly cellulose, chitin, polyoses, polyuronides, lignin, and lipoids. By far the larger part of the book is devoted to description of fine structure, and full use is made of results obtained with normal microscopy and microscopy by polarized light, with X-ray analysis, and finally with electron microscopy. A brief explanation is given of the powers and disadvantages of each of these methods when used on the cell wall, and a detailed discussion follows on the structure of primary walls, and on the vexed question of the mechanism of their surface growth. Finally there are accounts of specialized walls in many different groups of plants. A most satisfactory feature of the book is the very large collection of electron micrographs and other illustrations, chosen with much judgment and reproduced with beautiful clarity. This is a very desirable book for the botanist's library.

W. O. JAMES

PLANT-TISSUE CULTURE

La culture des tissus végétaux. Techniques et réalisations, by R. J. Gautheret. Pp. xviii + 863. Masson et Cie, Paris. 1959. NFcs. 105.00.

Any book with this title by Pro-

fessor Gautheret is assured of an interested and respectful welcome among botanists. The present volume has been conceived on a generous scale. It takes a wide sweep over its subject, cites nearly a thousand references, is copiously indexed, and is lavishly illustrated. Needless to add, it is a book of reference rather than one for casual reading.

The first section, running to over two hundred pages, is concerned with the technique of plant tissue culture. It deals in considerable detail with everything from the composition of culture media to the methods of handling materials of the most diverse kinds. It includes a list of all the known cultures that have been successful over long periods. It is probably this portion of the book that will be most frequently read. Later sections deal with morphogenesis and polarity, in so far as these baffling phenomena have been studied in tissue cultures. The general physiology and the pathology of the cultured materials then follow, with special reference to tumour formation. It is no denigration of Professor Gautheret to say that these last sections are comparatively thin in content. In spite of their obvious attraction as objects for physiological study, tissue cultures have not proved to be the most amenable of subjects, and not very much is yet known about how their metabolisms, for example, compare with those of normally situated tissues. Professor Gautheret's book will remain a standard reference until progress overtakes it.

W. O. JAMES

PLANT PATHOLOGY

Plant Pathology. An Advanced Treatise, edited by J. G. Horsfall and A. E. Dimond. Vol. I, The Diseased Plant. Pp. xiv + 674. Academic Press Inc., New York; Academic Books Ltd, London. 1959. \$22.

This is the first of three volumes on all aspects of plant pathology. It deals primarily with the diseased plant, and the first paper, by the editors, sets the scene for fourteen important papers by distinguished plant pathologists from a number of countries.

The following subjects are dealt with, all in great detail: the relations between plant pathology and other sciences; history of plant pathology; the recognition, diagnosis, and measurement of plant disease; how plants are directly affected by plant disease; histological, physiological, and biochemical aspects of the reactions of

plants to infection and invasion; hypersensitivity; predisposition; and the therapy of diseased plants. Each chapter ends with a selected but comprehensive list of references and is well and authoritatively written.

In their preface, the editors say that the main purpose of the treatise is to present general principles of plant pathology rather than to describe specific diseases and the methods used to control them. This first volume has done what it set out to do, and done it very well, and the editors and those who have helped them are to be congratulated on having produced one of the most important books on plant pathology to appear for many years.

R. K. S. WOOD

MARINE BIOLOGY

The Biology of Marine Animals, by J. A. Colin Nicol. Pp. xi+707. Sir Isaac Pitman & Sons Ltd, London. 1960. 95s. net.

Dr Nicol gives an extremely able general account of the biology of marine animals considered primarily, although by no means exclusively, from the standpoint of physiology. After introductory chapters on the marine environment and on the nature and control of the internal fluid environment in the population, he proceeds to deal with all aspects of physiology, from circulation to pigments, colour change, and luminescence. Passing beyond the usual confines of physiology, he concludes his long book with chapters on associations and on skeleton, shelter, and special defences. All is supported by extensive references to the literature and illustrated by numerous and well-chosen figures.

This is an impressive volume written with great care and bearing evidence throughout of first-hand research, wide reading, and notable powers of synthesis. No better single-volume treatment of the subject matter exists. All libraries and, if possible, all interested in the functioning of the wide diversity of animals that live in the sea should possess this admirable book.

C. M. YONGE

ANTIBIOTICS

British Medical Bulletin, Vol. XVI, No. 1, Antibiotics in Medicine. Pp. xvii+88. British Council, London. 1960. 20s. net.

This number of the British Medical

Bulletin gives a readable and well balanced picture of the present position of antibiotics in medicine and surgery, and an impression of the scientific and technological background to the rapid and complex developments in chemotherapy with which the antibiotics are associated. The first three of sixteen articles are concerned in turn with the chemistry and biogenesis of the antibiotics, with their mode of action, and with the mechanisms by which bacteria may acquire resistance to them. Professor L. P. Garrod and Dr. E. F. Scowen introduce the articles that follow, giving a lucid account of the principles involved in antibiotic therapy. Most of these articles are of a general nature. However, tuberculosis and bacterial endocarditis, two diseases in which prognosis has been greatly influenced by the use of antibiotics, are considered individually, and special attention is given to the difficulties presented by resistant staphylococci and gram-negative bacilli. The subjects have been chosen with care and are treated in a manner that maintains the traditional standards of the Bulletin.

E. P. ABRAHAM

HOROLOGY

Heavenly Clockwork, by J. Needham, Wang Ling, and D. J. Price. Pp. xv+254. Cambridge University Press, in association with the Antiquarian Horological Society, Cambridge. 1960. 65s. net.

This book, the first monograph of the Antiquarian Horological Society, embodies the results of one of the more remarkable recent discoveries in the history of horology. It used to be thought that the mechanical escapement was an invention of the Western world in about the last quarter of the thirteenth century A.D., and that the water clocks of earlier days were more or less simple forms of drip clepsydrae that moved pointers and automata by means of floats and pulleys but were devoid of any form of escapement. The authors now show that between A.D. 725 and about A.D. 1370 (when the art seems to have been lost) the Chinese constructed and operated elaborate astronomical clocks powered by water and regulated by an effective form of escapement.

The authors' discovery arose from their consideration in another connection of a book written by Su Sung in A.D. 1090; this described in consider-

able detail the method of making a mechanical armillary sphere and globe. The book had been known before, but its important position in the history of horology had not been appreciated, probably because the book had never been studied by those familiar with the history of horology as a whole.

The present volume includes a complete translation of Su Sung's third chapter, which describes his mechanism in detail, and contains a number of explanatory drawings in addition to reproductions of the illustrations in the original text. The authors have been able to identify more than 150 technical terms of early Chinese mechanics, and, armed with this glossary, they have been able to understand a number of other texts describing similar, and in many cases earlier, machines. There is a full account of the development of clockwork in China both before and after Su Sung and an attempt to link up the Chinese mechanism with the thirteenth-century water clocks of Western Europe.

C. B. DROVER

LABORATORY INSTRUMENTS

Laboratory Instruments, their Design and Application (second edition, revised), by A. Elliot and J. Home Dickson. Pp. xvi+514. Chapman and Hall Ltd, London. 1959. 55s. net.

This book, which deals almost entirely with the mechanical and optical aspects of laboratory instruments and materials, has proved to be a valuable and reliable guide to research workers and to others who need to design and construct special equipment. There are not many books of this nature, and the enthusiasm with which the first edition was received showed that it filled a definite need. The new edition includes a fuller account of plastic materials, corrosion-resisting metals, optical crystals used in spectrophotometry, and glass protection against radiation hazards, and new matter on colour vision, photographic lenses, and resolution tests. Among its many valuable features are the numerous charts and tables giving collected physical data for groups of related materials, and also the comprehensive lists of references appended to each chapter. It is an authoritative vade mecum for all who spend their time in physical laboratories.

W. C. PRICE

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

The Principles of Scientific Research (second edition), by P. Freedman. Pp. xvii + 227. Pergamon Press Ltd, Oxford. 1960. 25s. net.

The person for whom this book is intended is the young scientist who is considering becoming a research worker. It gives a survey of the nature of scientific research from the point of view of the person engaged in it, and describes the types of problem and the methods of attack. It also gives suggestions about the availability of support for research. The first edition has been revised by the author's son, R. Clayton, mainly so as to amplify the section on research in biology.

An Approach to Natural Science, by D. H. Brehaut, B. E. Dawson, J. L. Grimsdell, A. R. Paul, and J. E. Skull. Pp. 264. Methuen & Co., Ltd, London. 1960. 8s. 6d. net.

The authors have based this book on a two-year introductory course in science originally given at Quintin School, London. They have aimed at providing an introduction to the general study of science by interpreting the characteristics and mechanisms of living organisms in terms of physics and chemistry. Some of the chapters are on heat, food, the soil, and life cycles; the last two chapters, on electricity and on the nature of matter, are intended to provide links with specialist courses in physics and chemistry.

Quantum Chemistry: Methods and Applications, by R. Daudel, R. Lefebvre, and C. Moser. Pp. xiii + 572. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London. 1959. \$14.50.

This book is intended for chemists who wish to know how to calculate wave functions for molecules, and how to use these functions to study some of the physical and chemical properties of substances. The authors do not assume that the reader has a wide background in mathematics or quantum chemistry: such information is given, as required, in the book. The subjects covered include a survey of empirical methods in quantum mechanics, with a detailed study of the linear combination of atomic orbitals—molecular orbital (LCAO—MO) approximation and

briefier accounts of other methods, such as the valence-bond approximation; the section also contains a number of applications of these simple methods. The second part of the book deals with non-empirical and semi-empirical methods and includes a number of results of the application of these more rigorous techniques.

Flames: their Structure, Radiation and Temperature (second edition), by A. G. Gaydon and H. G. Wolfhard. Pp. xiii + 383. Chapman & Hall Ltd, London. 1960. 70s. net.

The aim of this book is to give a fairly advanced discussion of that part of the science of combustion that is concerned with stationary flames, with the emphasis on the physical rather than the chemical viewpoint. The subjects dealt with include: flow patterns and flame shapes, diffusion flames, and the measurement of flame temperatures. The progress of research in combustion has necessitated the rewriting of large sections of the first edition; two chapters have been completely rewritten so as to deal with rocket fuels and recent progress on flame problems.

Nouveau traité de chimie minérale, Vol. VII, edited by P. Pascal. Part I, pp. xxxix + 706. Part II, pp. 707–1473. Masson et Cie, Paris. 1960. Paper covers, NFcs. 180; bound, NFcs. 200.

F. Trombe, J. Loriaux, Madame F. Gaume-Mahn, and Mademoiselle C. Henry la Blanchetais have contributed the major part of this volume, dealing with the chemistry of scandium, yttrium, and the rare earths. The short section on actinium was written by G. Boussières.

Applied Organic Chemistry, by E. Kübler and D. M. Samuel. Pp. xi + 484. Macdonald and Evans Ltd, London. 1960. 50s. net.

This book is intended for students who need a link between academic textbooks of organic chemistry and detailed works on organic chemical industry. The chapters refer to a wide range of organic compounds, giving information on the industrial methods of preparation and separation: the book is arranged so that it can be used to supplement existing textbooks of organic chemistry.

Comparative Biochemistry and Physiology, Vol. I, No. I, edited by G. A. Kerkut and B. T. Scheer. Pp. 100. Pergamon Press Inc., New York; Pergamon Press Ltd, London. 1960. Subscription: Institutions, \$20 per vol. (two vols. per annum); individuals, \$15 per annum.

Professor Needham's foreword to this journal states that its aim is to publish papers devoted to the extension of the range of biochemistry and physiology, particularly to the invertebrates. The authors of papers in this issue include O. Lowenstein and L. H. Finlayson on the response of the abdominal stretch receptor of an insect to phasic stimulation, E. Baldwin on ureogenesis in elasmobranch fishes, and Professor Needham himself on properties of the connective tissue pigment of *Lithobius forficatus* (L.)

Ticks. A Monograph of the Ixodoidea. Part V, by D. R. Arthur. Pp. viii + 251. Cambridge University Press, London. 1960. 60s. net.

The first four parts—there are to be seven in all—of this comprehensive survey of the classification, structure, and biology of ticks were compiled by the late Professor G. H. F. Nuttall; the work is to be completed by Dr D. R. Arthur. The present volume deals with the genus *Dermacentor*, including sections on the American, Eurasiatic, and African species, and with the genera *Anocentor*, *Cosmiomma*, *Boophilus*, and *Margaropus*.

The Technique of Photomicrography, by D. F. Lawson. Pp. xvi + 256. George Neumes Ltd, London. 1960. 55s. net.

This book covers the technique of photomicrography, with the exception of electron photomicrography. Practical details of suitable equipment, illumination, and processing are given, to provide a complete guide for the scientist or photographer. A large number of photomicrographs are reproduced.

Biographical Memoirs of Fellows of the Royal Society. Pp. 280. The Royal Society, London. 1959. 30s. net.

There are 19 biographies in this volume, each accompanied by a photograph of the subject and a bibliography of his publications.

Notes on contributors

M. F. MADELIN,
B.Sc., A.R.C.S., Ph.D., D.I.C.,

Was born in London in 1931. He was an assistant in the herbarium of the Commonwealth Mycological Institute Kew, from 1947 to 1948; from 1948 to 1951 he read Botany at Imperial College, London, where he was subsequently appointed demonstrator. He joined University College of the Gold Coast (now Ghana) at the end of 1953 as Lecturer in Mycology; in 1955 he left to join the Royal Air Force. He rejoined Imperial College as a Lecturer in Mycology in 1957. He has worked on the physiology of fruiting in hymenomycetous fungi, but his principal research interest is the physiology of entomogenous fungi.

E. F. G. HERINGTON,
Ph.D., D.Sc., A.R.C.S., D.I.C.,

Was educated at the Royal College of Science, London. In 1937, after obtaining his Ph.D. degree, he joined the staff of the Fuel Research Station, Greenwich, and later was seconded to work for six years, on the mechanism of catalysis, at the Department of Colloid Science, Cambridge. In 1946 he transferred to the National Chemical Laboratory, Teddington, where he is Head of the Purification and Measurement Section. He is the author of numerous scientific papers and is co-author of a book on distillation.

N. G. STEWART,
M.A.,

Was born in Buckie, Banffshire, in

1916, and was educated at the local High School and at Aberdeen University. He first worked in the Reactor Research and Development Establishment, where he became a Group Leader in charge of the design of aerial and waveguide systems; he joined the Health Physics Division of the Atomic Energy Research Establishment, Harwell, in 1948, where he worked on a number of atmospheric diffusion problems. In 1958 he was appointed Head of the Health and Safety Division of the Dounreay Experimental Reactor Establishment. Later this year he will return to Harwell as Head of the Health Physics Division.

A. J. MARSHALL,
D.Phil., D.Sc.,

Was born in Sydney in 1911 and was educated at the University of Sydney and at Merton College, Oxford. His work has been mostly but not exclusively in the reproduction physiology of vertebrates in relation to the environment. He is now Professor of Biology and Comparative Physiology at Monash University in Victoria, Australia.

W. E. SWINTON,
Ph.D., F.R.S.E.

Was born in Scotland in 1900 and was educated at Glasgow University. He joined the staff of the British Museum (Natural History) in 1925. His main interest is in the fossil reptiles; he is the

author of several books on vertebrate palaeontology. He is Honorary General Secretary of the British Association.

J. E. LYNN
B.Sc.,

Was born in Newcastle upon Tyne in 1932 and was educated at the University of Durham, graduating in physics in 1953. He is now a Senior Scientific Officer at the Atomic Energy Research Establishment, Harwell, where he has worked on experimental and theoretical problems of neutron physics. He has been appointed a Resident Research Associate at the Argonne National Laboratory for a year, commencing September 1960.

P. H. GREGORY,
Ph.D., D.Sc.,

Was born in Exmouth, Devon, in 1907 and was educated at Brighton Technical College and at Imperial College, London. He was a research mycologist at Manitoba Medical College, Winnipeg, 1931-1934, and at Seale-Hayne Agricultural College, Newton Abbot, 1935-40. From 1940 to 1954 he was a research plant pathologist at Rothamsted Experimental Station, Harpenden. He was Professor of Botany at Imperial College, London, from 1954 to 1958. He returned to Rothamsted Experimental Station, where he is Head of the Plant Pathology Department, in 1958.

Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

GENERAL SCIENCE

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